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AN INTRODUCTION

TO THE

CHEMISTRY OF FARMING

FOR

PRACTICAL FARMERS.

BY

Right Hon. Sir THOMAS DYKE ACLAND, Bart.

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AN INTRODUCTION

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SPECIALLY PREPARED FOR

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WITH

RECORDS OF FIELD EXPERIMENTS.

BY

RIGHT HON. SIR THOMAS DYKE ACLAND, BART.

SECOND EDITION.

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1892.

Chem 558.92.3

IN

GRATEFUL MEMORY

OF

MY FRIENDS AND TEACHERS,

PHILIP PUSEY

AND

AUGUSTUS VOELCKER.

PREFACE.

THIS small book, on part of a very large subject, is published, in its present form, with the hope that it may help to give a practical direction to Technical Education in Agricultural districts. The writer is convinced that due weight must be given to experience, if Science is to improve Practice.

The accumulated experience of farmers is extensive; not always accurately recorded: the reasons are often far to seek. The Chemist tries to explain the reasons, but he needs to verify the results of his principles by experiments in the open field.

There is at present a general disposition among residents in the country to enquire into the facts and principles of Agriculture. But we must begin with the facts and work back to the principles. This little book is intended as a finger-post both for teachers and learners. In it will be found an attempt to answer the following questions:—

The products of the farm, food for man, and food for beast, containing the materials of fat, flesh, and bone—what are they made of?

From what sources do these materials come? what from the air, what from the soil?

What are the chemical elements of each product? and what are the universal laws of Nature by which those elements are combined, or the products decomposed?

In the present endeavour to suggest simple answers to these questions it will be found—

That no chemical element or compound is named which does not directly concern the farmer.

That every chemical formula is accompanied by a statement of quantities in common arithmetical figures.

That a practical explanation of scientific weights and measures is given in terms with which farmers are familiar.

The application of the principles, thus explained, to the manure of plants and the food of animals is pointed out in the words of the best authorities. A few suggestions for field experiments on ordinary farms and some records of results are added.

A short Chapter on the Theory of Atoms and Molecules is inserted; but it may be passed over on the first reading, as it is not essential to the understanding of the practical recommendations which follow.

The present attempt is the outcome of some forty years of intercourse with farmers and their scientific teachers, and of the endeavour to collect and diffuse information among a wide circle of friends. If I have retained the colloquial style which was natural when speaking to young men in the presence of their elders, I hope it will not be deemed unsuitable when submitted to the public in print.

I have endeavoured throughout to point in the notes to passages in works of authority, and of moderate cost, for definite information.

The substance of this Volume has already had a limited circulation, chiefly in the West of England, and has therefore been open to criticism. It has been carefully revised. I am deeply indebted to Professor Maskelyne, Dr. Voelcker, and Mr. Lloyd, for kind encouragement and corrections. But neither of those gentlemen must be held responsible for the whole as it stands, for I have in some cases thought it better to retain an old-fashioned or popular statement of facts, than to insert a more difficult exposition of recent theoretical doctrines.

For the insertion, at the end of the volume, of some extracts from Asa Gray on the life of vegetables and animals, and on the relation of Natural Science to Religion, I am wholly responsible.

Note.

In the Introductory matter (pages 2 and 3) I have directed special attention to one Elementary Primer on Chemistry, and to three Manuals on Agriculture.

If landowners resident in the country (Clerical or Lay), who may perhaps look at what I have written, desire fuller explanation, there is among the Text-books on Science in Longmans' series an excellent "Introduction to Chemistry," by my late friend, Prof. Allen Miller, of King's College, in whose laboratory I gained, more than forty years ago, the little practical knowledge of Chemistry which I have tried to turn to account in Agriculture. It was written expressly for beginners, and completed just before his death. (His large work in 3 vols. is still a Standard book.) This small book, beyond any with which I am acquainted, seems to be adapted to the use of the general reader who has had a good education. It is written in simple, pure English, dealing with tangible realities, never using a technical word without sufficient explanation, and introducing abstract principles gradually. Unfortunately, I did not discover the book till my own work was nearly completed.

Of the many books by eminent teachers on Chemical Theory, Chemical Philosophy, or Advanced Chemistry, it would be presumptuous in me to express an opinion. It seems to me that, in the desire to prepare students for higher branches of the Science, the authors generally introduce at an early stage subtle definitions and hypothetical principles which have but little present bearing on Agriculture, and which can hardly be intelligible to those who have done no work in the Laboratory.

But to all who desire to have a good library book, telling them what real Science has done for Agriculture, I heartily commend the Lectures of Mr. Lloyd, delivered at King's College, from which I have quoted several passages.

The two volumes, "How Crops Grow" and "How Crops Feed," by Johnson, are spoken of in the highest terms by Professor Gilbert, and are very practical. "Agricultural Chemistry and Geology," by the late Professor Johnston (of Durham) and D. Cameron, 13th Edition, 1882, is full of valuable information both on Chemistry and on practical Agriculture.

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INTRODUCTORY.

I WISH to make one more attempt, probably it will be my last, to assist my Agricultural friends to gather useful information from the accumulated result of the work done by scientific enquirers. The combined experiments conducted by practical men in conjunction with the Bath and West of England Society, and those of other Societies, especially in Norfolk, Essex, Cheshire, and North Wales, have awakened a wide-spread interest. I think there is an increasing willingness to believe that there is much to be learned beyond the repetition of each farmer's experience.

But it seems to me that to bring the results of science home to practical men, it is needful to translate some of the chemical language of the present day into the mother tongue. I have noticed that some of my friends are really desirous to know more of the meaning of the chemical principles now recognised than is conveyed by the usual recipes for manures. I confess that I have

found my self-imposed task more difficult than I expected. The whole vocabulary of Chemistry has been changed within the half century of the existence of the Royal Agricultural Society, to which Philip Pusey devoted the best sixteen years of his life uniting practice with science. Old principles have been modified by new discoveries and adapted to new theories, and great practical results in the way of technical work have been attained in other arts besides that of Agriculture.

I must begin by disclaiming all intention of attempting to teach what is called Scientific Farming to practical men. Neither do I suppose for a moment that the reading of a little book like this can do much for the education of the young. To learn chemical principles young men must go to work at experiments with their own hands in the laboratory. There are a number of excellent manuals and some very bad ones, which last seem to have an extraordinary run as cram-books for certain examinations. Such books make an old man marvel at the powers of memory which young ones can call into action.

I venture to advise any young farmer who desires to learn the first principles of General Chemistry, to obtain a copy of the *Science Primer on Chemistry* by Sir Henry Roscoe. It is impossible, I think, to imagine a more winning and skilful introduction to the study of Nature as

bearing on our subject, though it is not specially intended for an introduction to Agricultural Chemistry. It is published by Macmillan; the price is only 1*s*. I shall frequently refer to it for descriptions of well-known experiments illustrated by clear woodcuts.

Information on the three principal branches of Science in direct application to Agriculture may be found in three of the Handbooks of the Farm Series,* edited by our lamented friend and teacher, John Chalmers Morton, all written by masters of these subjects holding high positions.

Chemistry of the Farm. By R. Warington, F.C.S., F.R.S., one of the Rothamsted staff.

Life on the Farm—Plant Life. By Maxwell T. Masters, M.D., F.R.S., Editor of the 'Gardeners' Chronicle.'

Life on the Farm—Animal Life. By Professor Brown, V.S. of the Board of Agriculture.

To such manuals it is my main object to direct the reader; my subordinate aim is to assist practical men to understand the principles implied in these books, which, as Mr. Warington says, presume some elementary knowledge of Chemistry. I may add that in all these books there are some technical terms, well known in Science but not

* Vinton & Co., 2*s*. 6*d*. each.

explained by the writers. I hope by practical illustration to make these terms intelligible.

I do not attempt to give a systematic description of chemical elements or gases; still less to expound abstract principles arrived at by great thinkers. I propose to take some objects of everyday experience, animals and vegetables, and trace them backwards to their origin; and also to put into common words a few truths which in a hard scientific form repel the practical man.

I will then, in the hope that I shall have given a tangible meaning to some technical words, show the practical application of those truths to the manuring of crops and the feeding of animals, and conclude with some suggestions as to the verification of scientific principles by experiments in the open field on ordinary farms, and a record of such experiments as have come under my special notice during the last few years.

I hope for indulgence, if in the desire to be practical and simple I should appear to be sometimes not sufficiently precise or distinct.

PART I.

THE PRODUCE OF THE FARM—ITS CONSTITUENT MATERIALS WHENCE DERIVED.

CHAPTER I.

MEAT——MILK——VEGETABLES.

If we consider the production of animals ready for the butcher and for human food as the most advanced outcome of practical agriculture, we may try back to find out the steps by which we can attain our end. In other words, we may ask from what materials this animal structure is built up; that is to say, from what food the fat, flesh, and bone, are produced. First of all, the food of the young animal is its mother's milk, which therefore must contain fat, and flesh, and bone, or at least the materials for making them. We may enquire, by the way, whether we can increase the butter or the cheese in the dairy by regulating the food of the cow. We then have to ask what are the constituents of the vegetable food of the animal,

whether they are matured in the plant, or changed in the body of the animal. We must enquire from what sources do vegetables derive their nutrition; does their substance come out of the soil, or out of the air, or both? and how can we influence the quantity and quality of the vegetable food, either by manure or by any management of the soil, or of the growing plant?

In all these questions we must assume that animals and plants are making regular and healthy progress. There are, besides, many considerations as to the effect of diseases and of bad seasons. Into those important and sometimes anxious questions it is not proposed to enter here.

Meat, what is it?

To begin then with the fully-developed animal. The marketable produce to be sent to the butcher consists of three principal parts, the chemical constituents of which are distinguished by clear differences. Those parts are Fat, Flesh, Bone.

As regards man who eats the meat, fat is called, in all scientific treatises on food and cookery, a body warmer; fat burns, as we see in a tallow-candle, and leaves nothing in the form of ashes, nor does it when burnt cause a marked smell like burnt hair or wool. It has also been proved by the late celebrated Dr. Parkes, of Netley Hospital,

that fat and other compounds of like constituents, when eaten, will do muscular work; that is, produce and sustain force, as coal in a steam-engine generates force, and transmits it through the machinery.*

The lean meat, on the contrary, when burnt, is characterised by a particular odour like burnt hair, which the chemist recognises as an indication that there is in flesh a particular constituent which is not to be found in the fat. There is also another distinguishing feature. Flesh, if exposed to the air, begins in a few days to putrefy; fat does not so putrefy, as you may perceive by examining a jar of potted meat. The lean meat is preserved by a covering of clean fat, which does not putrefy, and does keep out the air from the meat. Flesh when burnt does not leave any considerable quantity of ash. But flesh burns very slowly.

Lastly, bone is principally composed of mineral matter. I speak of dry bone after the jelly has

* "According to the view propounded by Liebig, nitrogenous matter alone constitutes the source of muscular and nervous power. . . . Liebig's doctrine was at once accepted, and until recently had been looked upon as expressing a scientific truth."—Dr. Pavy, 'Treatise on Food,' 1874, p. 38.

I may record the fact that on the appearance of Liebig's doctrine, the late Lord Spencer wrote a letter to Mr. Pusey, which I saw, saying he was sure it was not true, and that it would some day be disproved by science. *See* footnote, p. 66.

For full explanation *see* Warington's 'Chemistry of the Farm,' cap. viii. p. 110.

been boiled out. The cartilage which by boiling becomes jelly or gelatine is similar as regards its chemical elements to the flesh; though doctors seem to doubt whether it is really nutritious, whatever the cooks may say about thick stock or calves-foot jelly.

The mineral matter of the bone is principally composed of phosphate* of lime, and a small quantity of ordinary carbonate* of lime.

There are also in various parts of the animal some small portions of sulphur, potash, and iron. Such then are the three constituent parts of the animal, we must not say exactly of animal food as eaten by man; for the mineral part of the bone, whatever it may do for the dog or the fox, is hardly food for man.

MILK.

Next comes milk. It is obvious that, as a human infant or a calf or lamb can be brought up on its mother's milk alone, this milk must contain the three substances of fat and flesh and bone in some form.

The fat in the butter burns away like the fat of the carcase, without smell and without ash. The cheesy matter (casein) is distinguishable by the same marks as the flesh. It soon causes milk to

* For the definition of these terms *see* p. 37.

turn bad or sour, it is in fact one main cause of bad butter, when not thoroughly washed out. There is left, when the cheese is burnt, a residue which corresponds to the hard part of bone.

In passing I may remark, as has often been said before, and cannot be repeated too often, how very important is skim-milk for the nourishment of poor children, containing as it does all that the growing body needs except fat, which can be bought in a cheaper form than butter, such as bacon or dripping.

Wheat—Turnips.

The same threefold division applies to vegetable food. If we take wheat, the staff of man, as a type, we can easily separate the flour into its corresponding constituents. Put a spoonful of whole-meal flour into a bit of muslin (or on a fine sieve) and pour water on it, or squeeze the cloth as long as a white liquid will come through. Allow the liquid to settle, when a fine white powder will fall to the bottom. This powder is starch; what is left in the muslin is chiefly gluten: starch and gluten are distinguishable like fat and flesh by the test of burning; the smell of burnt hair belongs to the gluten only, and when the whole, especially the gluten, is burnt, there will be a slight residue of

mineral ash corresponding approximately to the constituents of bone.

Now what is the principal element of the fat formation? Let us try a very simple experiment on the food of animals, roots (turnips or mangold).

Take 10 lb. of roots and slice them, and bake them in a hot oven, till they are black; then weigh them again, you will find only 1 lb. In other words there has been 90 per cent. of water removed by evaporation, simple drying. The black stuff left is chiefly charcoal or *carbon.* Burn that black stuff in an iron pot or ladle, and you will find one tenth of a lb. of ashes. That is to say, in a ton of roots you have only 2 cwt., or 10 per cent., of dry solid matter, and of those 2 cwt. only about 20 lb., or 1 per cent. of the whole produce, is directly drawn from the hard materials of the soil.

In this hasty analysis of roots, I have not drawn any attention to the distinction between fat-formers and flesh-formers. I want to impress on you the fact how very small is the earthy or mineral matter which comes out of the soil, and to show that the bulk of the dry matter after the water has been evaporated, is carbon.

Where then are we to look for the answer to the questions contained in the title of two excellent books, 'How Crops Grow,' and 'How Crops Feed'?

I might have gone on to show you the different

elements of food in barley, oats, beans; in hay and straw, and in various so-called artificial foods. But we may come to these details further on.

First let me put before you the substance of what I have said so far, in a tabular form which may help your memory.

	A	E	O
Meat ..	Fat	Flesh (lean) ..	Bone (dry).
Milk ..	Butter	Cheese (skim) ..	Mineral ashes.
Wheat ..	Starch	Gluten	Ditto.
Distinctive characters.	Easily burn. Do not easily putrefy. Do not give off ammonia.	Do not easily burn. Do putrefy. Do give off ammonia.	Do not burn at all. Do not putrefy. Do not give off ammonia.

The vowels A, E, O, occur respectively in the words, fat, flesh, bone, and may serve as an aid to the memory.

The Four Elements (of the Ancients).

In a short paper* which appeared in the Bath and West of England 'Journal' a few years ago, a reference was made to the old idea of the four

* That paper will be found in Part IV. of this volume. It would perhaps be worth while to look at it before reading on at this place, notwithstanding some repetition.

Elements (so called), Fire, Air, Water, and Earth, as illustrating the action of heat or sunshine, the inhaling of what used to be called *carbonic acid gas* from the atmosphere by the leaves of plants, and the use of water as the means by which they draw some solid matter up through their roots, from the soil.

It is now proposed to carry on this illustration a little further in a homely fashion; using very plain words as an introduction to what, if the reader is not tired, he will find further on; namely, some explanation of the scientific terms which are commonly introduced by writers on what is called the Science of Agriculture, or Agricultural research.

I must frankly confess that on former occasions I have been, perhaps unduly, prejudiced by the introduction into writings intended for practical farmers of new terms which seemed to me more likely to astonish or to repel, than to instruct.

But I am bound to admit, after some careful study, that the progress of Chemistry has made a great change of language unavoidable, and that the modern nomenclature is truer and more instructive than the old. It is also evident that all young persons who aspire to pass examinations either in the Science Schools, or with a view to qualify for some professions, must learn the new language, whether they really understand it or not.

It will be my endeavour to help the young farmers at least to attach some practical meaning to words which are now generally adopted in Agricultural works of the highest authority.

But before we embark on this technical voyage towards a new and unknown country, let us first go on talking plain English for a few pages; and, as we go on, let us make acquaintance with a few capital letters, and figures of a mathematical look, which, if used too freely at first, only repel the learner.

The plan usually adopted in chemical lectures and text-books is to exhibit or describe experiments; showing in detail the behaviour, as it is called in the laboratory, of all the known elements (about seventy), and all their possible combinations: and also to lay down in very precise and abstract scientific terms certain fundamental laws of nature. The bearing of these laws on the facts of common life usually comes later.

When Chemistry is taught as a branch of general or professional education, with a view to the training and discipline of the mind, this may be the right course for the teacher to adopt. But I think it is not the way to help the practical farmer to understand the reasons of his own practice, or to improve upon it. In the first place, he has not access to chemical laboratories. His farm is his laboratory; and if he has not an exact

or precise knowledge of causes, he has a very practical experience of results. At first sight, gases and symbols seem to him vague and unmeaning. It seems better to *begin with experience and work back to principles.* This is called the *analytical* method, as distinguished from the *synthetical* or building up method; as if we took to pieces an old machine, in order to understand how each part works, and to be better qualified to repair it and put it together in good working order.

To the question "How plants grow?" proposed at the foot of page 10, some answer will be given further on (p. 23, and p. 33), showing analytically from what elements and compounds plants derive the principal part of their substances.

At the end of the volume will be found extracts from a charming work by the late Professor Asa Gray, Darwin's friend, explaining in a complete but concise form how these elements are built up by the action of life in the form of *Protoplasm* or *Bioplasm,* as it is called (with reference to animals), by Professor Brown.* Bioplasm is the preferable term, as it involves no assumption as to the origin of life. It only implies that where life is, there is the *plasma,* or formative matter. See Appendix I., p. 197.

* 'Animal Life on Farm,' p. 2, and specially cap. viii. p. 97.

CHAPTER II.

WATER, AIR, AND WARMTH.

LET us begin with Water (we will come to *heat* or *fire* presently). What is water? I mean pure water. Spring water and river water are not pure water, they always contain some mineral matter, and often some gas, and vegetable or animal matter. Rain water is nearly pure, not quite.

We must first grasp firmly an idea, not obvious to every one. *Solids, liquids, gases, are not different things.* They are different *states* of the same things. *Pure water is not always a liquid.* It is so at ordinary temperatures. If water is heated enough it becomes a gas called steam; if it loses enough heat it becomes a solid. Water gives off steam, gas, or vapour from its surface at all temperatures; but the temperature at which it boils does not depend only on heat; pressure must also be taken into account. On the tops of very high mountains water boils at a lower point, because the pressure of the air is lighter. But we need not dwell on these points for our

present purpose, important and interesting as they are.*

What is water made of? is it a simple element which cannot be decomposed? No. It is not simple, it is made up of two elements, which, when free or uncombined, are gases. This was discovered only just one hundred years ago. As to the meaning of the word "element," see note below.†

One of these gases was at first called "Vital air," as being necessary for the breath of life‡ (we shall presently hear of another kind of air called "fixed air," p. 20). But this vital air soon acquired the name *Oxygen*, because it was supposed to be the generator of acid (Oxy- being Greek for sharp or sour). This doctrine about acids is now abandoned. But we shall see that oxygen enters into almost all things. More than one-third of the weight of the world is oxygen.

* One of the standard works on Chemistry, by Fownes, edited and enlarged by Watts, opens with these words:—"It is of great importance to understand clearly what is meant by the terms *density* and *specific gravity*." But it is very difficult for the untrained mind to understand the explanation merely by reading.

† Sir Henry Roscoe thus defines *element* and *compound*:—

1. Simple bodies or elements—substances out of which nothing else can be got.

2. Compound bodies—substances out of which two or more different things can be got.—'Primer,' § xvi. p. 75.

‡ It is sometimes called "burning air;" that is, air which makes something else burn. It is different from "*inflammable*" air; that is, air which can be set on fire and itself burns.

Oxygen is the most important and most abundant of the elements. It is more than one-fifth of the bulk of the air. It is eight-ninths of all the water in the ocean; clay, limestone, and sand contain about half of their weight of oxygen. It also enters largely into vegetable and animal substances.*

The other gas of which water is made is of special importance in chemistry, as it is the lightest substance (capable of being weighed) in the universe, as far as we know, and therefore the unit of all comparative weights and measures. It used to be called "inflammable air." It is, in fact, an important element in the flame of candle, lamp, or coal. But it soon acquired the name *Hydrogen* (Hydro being Greek in composition for water) as the generator of water. It is also very important as a component of all vegetables and animals, and is therefore diffused throughout nature.

These two gases can be shown to rise out of water by a very simple and beautiful experiment.† The two gases, Oxygen and Hydrogen, may be collected in two inverted glasses or closed tubes; and, observe, one tube gets twice as much gas as the other tube, as regards space, bulk, or what chemists called *volume*, not weight. If there is half a pint in one tube, there will be a pint in the other—the half pint will be Oxygen, the whole

* Miller's 'Text-book,' p. 26.
† Roscoe's 'Primer,' "Water," § vi., Experiment 12.

pint will be Hydrogen—this, you observe, is measure, not weight. But now for weight. Chemists can weigh gases easily; the oxygen, though only half the bulk, is eight times the weight of the hydrogen, so that volume for volume it is sixteen times the weight of the hydrogen.

Now this fixed relation between the weights of different substances when united in a compound is of the utmost importance, it is a fundamental principle of chemistry—the extent of its application is very far reaching.

AIR.

We must now speak of the Air or Atmosphere. The atmosphere *contains* two gases; observe I do not say is *composed* of two gases, because the air is not a fixed *chemical compound;* it is only a *mixture.* We shall see presently what we mean by a compound.* Vital air, then, or oxygen, is part of the mixture; it is what is essential to our lives when we breathe; it is what is essential to the flame of the candle and the burning of coal in

* As to the distinction between *elements* and *compounds*, see opening chapter of Miller's 'Text-book,' p. 3, and as to *mixture* and *combination*, p. 14.

A glass of grog—containing alcohol, sugar, and water, is only a *mixture.* A saline draught, or a seidlitz powder dissolved, is a *compound.*

the fire. If there were nothing else in the air to dilute this inspiriting life-exciting air, we should go off in a few minutes into a fever and die.

The other gas is called *Nitrogen*, because it was found in Nitre or Saltpetre. As it exists in the air (only mixed not united) with oxygen, it appears to act merely in the way of diluting the active vital air. We shall learn presently the paramount importance of nitrogen to the agriculturist; and its powerful action when in *chemical combination* with oxygen; but it is rather shy of union with other bodies. When we come to speak of *Ammonia*, *Nitric Acid*, and *Nitrates*, the value to the farmer of nitrogen will be plain.

The proportion of oxygen in the air is about one-fifth by measure, that of nitrogen about four-fifths.* But in 10,000 measures of air there are from four to six measures of another gas, to which I must now ask your special attention.

Strange indeed as it may seem, this small proportion of gas is what forms or feeds the bulk of

* Miller ('Text-book,' p. 40) gives the composition of the air *by measure*, in a litre or 1000 cubic centimetres, as follows (for these measures, see p. 25):—

Oxygen	206·1
Nitrogen	779·5
Aqueous vapour (about)	14·0
Carbonic anhydride	·4
Nitric acid, ammonia, carburetted hydrogen	traces
	1000·0

the vegetables, and through them all the animals on the earth. This gas was called "fixed air," when it was first discovered. It is this gas which is driven out of limestone in the lime kiln; it is the deadly gas found sometimes in deep wells, and in the bottom of brewers' vats; it is the unwholesome air in a crowded room, for it is the gas exhaled from the lungs, after the oxygen of the fresh air has been inhaled and come into chemical union with carbon in the blood; it is the gas which is produced by the burning of coals, and candles, and charcoal. But, nevertheless, it is the source from which, if you omit water, much more than half the dry matter of all your crops and of the bodies of your live stock is derived.

You have often heard this gas spoken of as *Carbonic Acid gas.* In modern chemistry it has taken a new name; indeed more than one name,* which is rather puzzling for young farmers, but in this transition of names (troublesome as it is to old stagers also) we really see the growth of sound theory, and the advance of knowledge and the understanding of facts.

As to the nature of this carbonic acid gas, I will only say at present that it is a chemical *compound*, not a mere *mixture* of carbon and oxygen. This compound is made up in strict union when a

* Carbon-dioxide, or carbonic anhydride. See p. 44.

portion of coal or oil, or other substance containing carbon, is raised to a certain heat in the open air.

Fire or Combustion.

And now we may answer the question above postponed, what is fire? more precisely, what is flame? or, as it is sometimes expressed, what do we mean by combustion or burning? We mean *chemical union*, which is generally accompanied by *heat*, and in this case by *light* also. The minute particles of carbon heated up to a certain point in a fire or flame already burning are raised to a greater heat on coming into contact with the oxygen of the air, but the outside zone of the flame is not the most luminous part of the flame. There is also some hydrogen in the oil or coal, and when that comes into contact with the air it forms water. This you may see by holding a cold glass for a second or two over a candle, when you will see water condense on the cold glass.

It is very important that you should understand what happens when a candle burns. Nothing is really lost. A simple experiment described by Sir H. Roscoe shows that in fact some weight is gained, for the substance of the candle has now united with it some oxygen from the air. The carbonic

acid gas and the water so formed, can be weighed.*

Sir H. Roscoe also shows that although carbonic acid is an invisible colourless gas, some of the carbon in the flame of the burnt candle can be detected as smoke or soot.† Other experiments show how carbonic acid unites with the lime in clear lime water, which then becomes milky, because it contains some solid matter which will settle down at the bottom of any vessel.‡

Carbon.

I hope now you are satisfied that in the carbonic acid gas there may be some solid matter for the vegetables to feed on. You may have a further proof in the growth of mustard and cress on flannel.§

Sir Henry Roscoe thus draws out the lesson of this experiment:—

"Whence did the growing plants get the materials necessary to form their stalks and their leaves? not from the flannel, for that remains unchanged; not wholly from the seeds, for the plants weigh much more than the seeds; not from the water alone, because the plants are building up

* Roscoe's 'Primer,' § ii., Experiment 3, p. 14.
† Ibid. § i., Experiment 1, p. 11.
‡ Ibid. § iv., Experiment 7, p. 24.
§ Ibid. § v., Experiment 8, p. 26.

stalks and leaves containing carbon, and this substance is not present in water. Where does the plant get the carbon it needs? From the air, we answer. A previous experiment, No. 7, showed that animals are continually giving out carbonic acid gas, and we are therefore sure that this gas must be present in the air, although perhaps in small quantity."

The action of carbonic acid underground on the soil is very important to the farmer, and, probably, also on the surface when water from drains or springs is used for irrigation.

We have now made some slight acquaintance with the four principal elements of vegetables and animals—namely, *Oxygen*, *Hydrogen*, *Nitrogen*, and *Carbon*. Before we go on to speak of other elements, we must learn something of the principles by which these and all elements are united in accordance with fixed universal laws of Nature.

It may be convenient at this point to introduce a short account of the weights and measures now adopted in all scientific books on chemistry. Although I have not introduced them into the text, they are used in books from which extracts are quoted in the notes.

Perhaps I may render some little service to young learners if I give a popular (not an exact or complete) comparison of these weights and measures with those in common use in England.

INTRODUCTORY SECTION

TO

CHAPTER III.

The Metrical System.

The system now generally adopted (on account of its great convenience) is based on the French metre.

The Metre is approximately $\frac{1}{40,000,000}$ part of the circumference of the earth.

The metre is very nearly 40 inches long—39·37 inches.

All other measures are derived from the metre. *Measures of length* are obtained either by multiplying the metre successively by 10, or dividing successively by 10.

Measures of capacity are also derived from the metre. A cubic vessel whose sides are the tenth part of a metre, nearly 4 inches wide and deep, is called a *litre*, which holds a little more than one pint and three-quarters, rather more than the reputed quart of a sherry bottle—1·76 pint.

The Metre is divided into a thousand millimetres, commonly printed m.m. in chemical books. Ten millimetres (or one hundredth part of a metre) are called a *centimetre.*

The Litre, in like manner, is divided into a thousand little cubes, sometimes called millilitres, more commonly called *cubic centimetres*, or c.c. The side of each of these little cubes is rather more than $\frac{3}{8}$ of an inch, rather less than $\frac{4}{10}$ of an inch. One cubic centimetre of distilled water* weighs *one gramme.*

The three measures, then, to be kept in mind are the *millimetre*, m.m.; the *cubic centimetre*, c.c.; and the *gramme.*

In passing, it may be remarked that all travellers on the Continent are familiar with the kilometre, a thousand metres, about $\frac{6}{10}$ of a mile, or 1093 yards; and the kilogramme, a thousand grammes, about two pounds and two-tenths—both spoken of as the kilo.

A thousand kilogrammes (or a cubic metre) are approximately equal to a ton, and may be compared with a cubic yard of earth or a cartload.

English Imperial System.

The English imperial weights depend on the weight of a certain measure of distilled water, at the sea-level in London at 62° Fahrenheit, and 30 inches on the Barometer.

The measures depend on inches marked on a

* This is pure distilled water at 4 degrees on the Centigrade thermometer, for explanation of which *see* page 29.

pendulum swinging seconds* at the same place and temperature. The measure of water is a gallon, measuring 277·274 cubic inches; the weight is fixed at 10 lb., or 70,000 grains.

It is well to remember that there is a point at which the French and English measures can be compared without fractions, or rather with so very small a fraction that it may be left out of account for most purposes.

$$\left.\begin{array}{c}\text{100 Litres,}\\ \text{or}\\ \text{100,000 grammes,}\end{array}\right\} = \left\{\begin{array}{c}\text{22 Gallons,}\\ \text{or}\\ \text{1,540,000 grains.}\end{array}\right.$$

Divide both sides by 100,000, or strike off five figures, and we have the unit, 1 gramme = 15·4 grains.†

The merit of the metrical system is that the *cubic centimetre*, c.c., or the thousandth part of a litre, is the simple unit of weight, namely, 1 *gramme.*

One great inconvenience of the English system, especially for scientific use, is that the smallest solid unit and fluid unit do not agree.

The solid ounce is divided into 437·5 grains. The fluid ounce is divided into 480·0 minims.

* It is curious that the length of this pendulum differs by a small fraction from a French metre, 39·13, as compared with 39·37.

† A comparison of *Measures of Area* in round numbers is given at the foot of the Diagram on the opposite page.

DIAGRAM

SHOWING THE COMPARISON

BETWEEN THE ENGLISH AND THE METRICAL MEASURES.

The boundary lines of this square measure one-tenth of a metre.

The line on the right hand is divided into 10 centimetres, or 100 m.m. (millimetres).

The little square at the foot of the right hand is a square centimetre, a cube on that square is the unit of measure and weight.

On the left-hand line inches and half-inches are marked.

The little square at the foot on the left is a square half-inch.

A cubic inch . . .	contains	16·88 c.c.
A cubic half-inch . .	„	2·11 „
A drachm or teaspoonful	„	3·55 „

The cubic centimetre (c.c.) therefore is, roughly speaking, about half of a cubic half inch, and rather less than one-third of a teaspoonful.

A millimetre (or a tenth part of a centimetre) is almost exactly $\frac{1}{25}$ of an inch.

In other words an inch is nearly the same as $2\frac{1}{2}$ centimetres, or 25 m.m.

English Measures of Area.			For approximate comparison.	Metrical Measures.
Unit one perch	=	$30\frac{1}{4}$ sq. yds.	4 perches / 121 sq. yds.	Unit Are = 100 sq. metres,
$\frac{1}{10}$ of Acre . / 1 sq. chain .	=	16 perches / 484 sq. yds.	400 perches / 12,100 sq. yds.	One Hectare = 100 Ares (2·47 acr. = 11,960 sq. yds.)
Square furlong / Ten-acre field .	=	100 sq. chains =	48,400 sq. yds.	= 4 Hectares (nearly).

Consequently, as Mr. Squire points out in his 'Companion to the Pharmacopœia,' the minim of fluid is not of the same capacity as what he calls the grain-measure.

The minim = ·91 parts of a grain of water.

Instead of going into details and long tables of decimals, which can be found in any good modern book on arithmetic, it may be more to the purpose to set down a few practical equivalents for the figures in chemical books. The terms decilitre, centilitre, millilitre, are not much used.

Half a litre is usually called	500	c.c.
Three quarters " "	750	c.c.
An English pint, 20 fluid ounces ..	567	c.c.
One fluid ounce	28	c.c.
One drachm, 60 minims	3·55	c.c.
One English cubic inch	16·88	c.c.

It is important to note, as already said, that one gramme (the basis of all weights) of distilled water is one c.c.

There is also a little weight, invented by Dr. Hoffmann, the great promoter in England of modern chemistry. It is the weight of a litre of hydrogen gas, which is 0·0896, less than $\frac{9}{100}$ of a gramme. This is now adopted as the unit of gas calculations. It is called a *crith*, from a Greek word for a barleycorn. Dr. Hoffmann told his pupils to inscribe this figure as with a sharp graving tool on their memories. Again, he says,

"Do not lose this figure 0·0896 ; have it ready at a moment's notice." *

Measures of Temperature and Atmospheric Pressure.

Thermometer.

In modern chemical works the scale of the ordinary English Thermometer (Fahrenheit) is rarely used. That scale begins at 32 degrees below the freezing point, and rises to 212 degrees for the boiling point. The interval between the freezing point and the boiling point is divided into 180 degrees.

On the scale almost always used in chemical books the interval between the freezing point and the boiling point is divided into 100 degrees (beginning at zero freezing and rising to 100 degrees boiling). This scale is called the Centigrade scale.

It follows that 5 degrees on any part of the Centigrade scale are equal to 9 degrees on the Fahrenheit scale. But, as the scales do not start from the same point, the 32 degrees below the freezing point have to be added to the corresponding degrees on the Fahrenheit scale, counted from the freezing point upwards.

* The reason why this figure is so important is because we learn the weight of a litre of any gas, if we multiply its combining number by this figure.

Thus 15 degrees (3 × 5) Centigrade correspond to 27 degrees (3 × 9) Fahrenheit above the freezing point (0 Centigrade), to which must be added 32 degrees, or

15° C. = 27 F. + 32 F. = 59 F.

Two points often referred to on the English scale are represented thus :—

60 Fahr. = 15·5 Centig.
62 Fahr. = 16·6 Centig.

Another point of special interest is the temperature at which water weighs heaviest, or the point of the "maximum density" of water—

4° Centig. = 39·2 Fahr., or 7½ degrees above Freezing.

In medical books the temperature of the human body is given *—

Normal, in Health, about	98·6 Fahr.	= 37 Centig.
High Fever, about	104 Fahr.	= 40 Centig.

Barometer.

The height of the Barometer is also usually expressed by the fractions of a metre, not by inches ; 30 inches, as already explained, are a little more than ¾ of a metre. So on the Barometer

0·76, or 760 m.m., corresponds nearly with 30 inches (accurately 29·92).

* Landois and Stirling's 'Text-book on Human Physiology,' p. 413.

CHAPTER III.

CHEMICAL PROPORTIONS AND CONSTITUENTS.

I STATED a little earlier that oxygen and hydrogen united in water in the exact proportion by weight of 1 to 8; for reasons which will be given further on, it is now always stated that the proportion is by weight 2 : 16. Hydrogen (a single dose) is always counted as *one*, every other element has its number. Oxygen is, as stated above, p. 18, bulk for bulk, sixteen times as heavy as hydrogen; in the case of water there is what, in unscientific language, I may call a double dose of hydrogen.

The figures which follow may represent grains, ounces, or pounds, in fact any weights; the *proportion of weight* is the point. The *proportion of volume* or measure is quite another matter, and more difficult.

Hydrogen.		Oxygen.		Water.
(*Double Dose.*)	+	(*Single Dose.*)	=	(*Compound.*)
2		16		18

In the case of carbonic acid gas (as it used to be called), there is a union of one dose of carbon with

a double dose of oxygen. The combining proportion of carbon is 12, that of oxygen 16, as above stated; we have therefore

Carbon.		Oxygen.		Carbonic Acid.
(*Single Dose.*)	+	(*Double Dose.*)	=	(*Compound.*)
12		32		44

Now this proportion is always maintained for this compound. There is another compound of carbon with a single dose of oxygen; but that is not a food of plants, so we will not say more about it now (*see* page 44). It used to be called carbonic oxide. It may be seen in the fireplace when the fire burns blue.

There is another compound of which you have often heard, that is *Ammonia*; that also has had to undergo, if not a change of name, at least an important change of relationship. But let me speak of it first in its old style. I told you that nitrogen was an important food of plants; they cannot get it direct from the air in its simple form. It comes to the service of the farmer at first in the form of ammonia, and probably has to make another change in the soil, or two changes before it becomes plant food.* Ammonia is composed of a single dose of nitrogen, and a triple dose of hydrogen. The combining number of nitrogen is 14, that is, a pint of nitrogen is fourteen times as

* See Chapter X. on the Action of Manures.

heavy as a pint of hydrogen. The compound is thus formed—

Nitrogen.		Hydrogen.		Ammonia.
(*Single Dose.*)	+	(*Triple Dose*)	=	(*Compound.*)
14		3		17

You often see at the foot of an analysis a certain percentage of nitrogen with a further entry "equal to ammonia, so much;" the proportion is always, nitrogen, 14; ammonia, 17.

We have now learned something of three compounds essential to plant life—namely, water, carbonic acid, and ammonia.

Volatile and Solid Constituents.

Thus far we have been engaged with what are sometimes called the *volatile* constituents of plants and animals. By volatile we mean, first, that they are directly or indirectly derived from the atmosphere; and secondly that, when life is extinct and decay or putrefaction ensues, these constituents are again dispersed in the form of gases; only a small quantity of ashes being returned to the earth. I ought perhaps to include two more constituents, *Sulphur* and *Phosphorus*. When we come to speak of the compounds forming parts of animals, we shall find that sulphur always enters into the flesh (and therefore into some kinds of vegetable food)

to a small extent, and into hair and wool to the amount of from 3 to 5 per cent. Phosphorus (an element which readily takes fire, and burns into a white substance, containing two doses of phosphorus and five doses of oxygen), enters into plants and animals chiefly as phosphate of lime, of potash, of soda, or of magnesia.* And in these forms it may be found in their mineral ashes.

Minerals.

We will now pass on to the *non-volatile* parts of plants. Those constituents of plants are to be found in the ashes left after burning. They are almost entirely minerals. Some of you may be old enough to remember that Liebig put forward a mineral theory of manure, and even proposed a patent mineral manure, consisting of the elements of plants as found in their ashes. That proposal led to the famous controversy with Sir John Lawes, referred to further on.† The mineral manure has long been forgotten; but the scientific work of Liebig has been most instructive, and the practical but not less scientific conclusions established by Sir John Lawes are the foundation of modern agriculture.

* See Johnson, 'How Crops Grow,' chapter ii., "Ash of Plants," p. 44.

† Chapter ix. p. 89.

SALTS.

Carbonates—Phosphates—Sulphates—Nitrates.

I place the word Salt before you prominently. First of all because you are familiar with common table-salt.

Secondly, because the greater part of the solid matter on the earth is in the neutral condition, to which chemists have applied the word *salt.* Most salts are neither acid, nor the opposite of acid, but neutral. Sweetness, like sugar, is not the opposite of any acid. We mix sugar with lemon in punch or lemonade; we mix oil with vinegar in making a salad—but neither of these mixtures alters the nature of the acids. These are *mixtures,* not *compounds.*

On the other hand, either lime, or potash, or soda, has a special effect on acids, which is called neutralizing the acid; the result of mixing them with acids was found to be a compound which was called a salt. Common salt was supposed to be a compound of *hydrochloric* or *muriatic* acid (the spirits of salt of the shops) and soda. That supposition was found out by Sir Humphry Davy, the immortal founder of agricultural chemistry, as Liebig called him, not to be true. He proved salt to be composed of two single elements, *chlorine* and *sodium.* The chlorine has no hydrogen com-

bined with it, and is not an acid; the sodium has no oxygen, and is not a base (or alkali).* (See p. 40.)

BASES.

I should here call your special attention to the important word "*Base.*" Whenever you hear or read of *nitrate of soda, sulphate of ammonia, phosphate of lime*, you may assume that the first word ending in "ate" represents the presence of an Acid (generally a strong acid), and that the second word (after "of") implies the presence of the Base combined with that acid, so far as regards the particular compound. Of course the same base may also be combined with other acids in other compounds. Any of you who have read about Sir John Lawes's experiments, must be familiar with the expression, "salts of ammonia."

Professor Crum Brown says simply, "when an acid and a base are mixed a salt is produced." He also defines acids and bases as "substances opposed to one another in chemical character, and capable of acting upon one another, so that both the acid

* It was usual to speak of the bodies which I have called "opposite of acid," and which, if soluble, have a taste like that of wood-ashes or burnt lime, as alkaline. Ammonia was called *volatile alkali*; potash and soda were called *alkalies* (or *fixed alkalies*); and lime and magnesia were called *alkaline earths*. Stockhardt's 'Agricultural Chemistry,' edited by Henfrey, 1855, p. 21. Brande, chap. vi. p. 594.

and the basic properties are neutralized, and salts produced."*

The name Salt then, having been adopted, is retained for a number of substances found in nature (such as limestone, or carbonate of lime), which substances have been analysed by science and found to consist of an acid and a base, and for a number of compounds produced by art from the union of acids with bases.

You may take as instances of a natural salt, common limestone or carbonate of lime (if I may be allowed to call carbonic dioxide an acid when dry), or again gypsum or sulphate of lime. As a sample of artificial salts, I might mention a common saline draught. An endless variety of artificially formed salts is produced by the chemist, generally, however, by the mutual interchange of acids and bases in salts brought together in solution.

Superphosphate of lime is a highly complex salt, but to avoid confusion it will be better not to explain its composition here (*see* footnote †).

The following may be taken as examples of each

* The reader may be specially referred to Professor Crum Brown's 'Elementary Manual' (Chambers' series), section xvii. pp. 16–18, for a simple account of acids, salts, and bases; and for an explanation of the terminations in common use, such as sulphide and sulphate, sulphurous and sulphuric.

† The explanation is given fully in Lloyd's 'Lectures on the Science of Agriculture,' chap. xi., delivered at King's College.

of the component parts of salts (acids and bases) with the names of which you are familiar.

ACIDS.

Popular Name.	*Scientific Name.*
Oil of Vitriol	Sulphuric Acid.
Aquafortis	Nitric Acid.
Spirits of Salt, or Muriatic Acid ..	Hydrochloric Acid.
Vinegar	Acetic Acid.

BASES.

Popular Name.	*Scientific Name.*
Quicklime	Calcium Oxide.
Potash	Potassium Oxide.
Soda	Sodium Oxide.
Magnesia	Magnesium Oxide.

We may speak first of the Bases, as they are the simpler bodies. I have attached to them the modern names; they used to be called oxide of calcium, &c., but I avoid that form for fear the words "oxide of" should be understood like "sulphate of," suggesting the presence of an acid. These bodies, calcium oxide, &c., like common salt, which is now called sodium chloride, are very simple, and show the union of only two elements.*

Ammonia, which is a powerful base, is not put into the list because of the special theoretical name, ammonium,† which includes not oxygen, but

* Words ending in "ide," imply the presence of two simple elements in a compound, as words ending in "ate," denote the presence of a compound acid.

† The scientific names of metals end in "um," taken from

another dose or equivalent of hydrogen, and will be referred to later.

A beautiful experiment, which can be easily shown by any chemist or druggist, illustrates the oxides of metals.

A red powder known as "red precipitate" in shops (mercury oxide), when heated over a lamp in a small glass tube (a test tube), can be split up, forming little bright drops of quicksilver, and oxygen gas; this gas is shown by causing a red-hot splinter of wood, when placed in it, to burst out into flame.*

This process of separating oxygen from a metal is the same as takes place when iron ore, which is an iron oxide, is smelted; it is called "reduction." The union of oxygen with another substance is called "oxidation." When iron rusts, it is oxidized and becomes heavier.†

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the Latin words, aurum, gold; argentum, silver; ferrum, iron; hence the name ammonium was invented because it is supposed to act like potassium, a metal. Gypsum, though ending in "um," is not a metal.

* Roscoe's 'Primer,' § xiii., Experiment 30, p. 60. See also p. 108.

† "We have seen that many bases are oxides of metals. We must bear in mind the relation of metals to their oxides.

"When a metal or other substance is made to unite with oxygen it is said to be 'oxidised'; when the oxygen is taken away from an oxide and the original substance, whether metal or not, is reproduced, the oxide is said to be reduced." —Crum Brown, p. 34.

The whole section is very instructive.

As you are familiar with quicklime, it may be well to note that, if quicklime remains exposed to the air, it gradually becomes slaked, and absorbs carbonic acid and water; that is, it partly returns to its former condition of carbonate of lime, partly becomes what is called *hydrate of lime* by absorbing water. This is also sometimes called *hydroxide.**

Other bases are also oxides of metals, that is, they are compounds of a metal, and of oxygen, and each of them has its fixed proportion by weight to hydrogen as the unit, and to every other substance. But the constitution of the well-known substances caustic soda and caustic potash differs from the oxides of potassium and sodium as slaked lime differs from quicklime (calcium oxide) by being combined with water; they are altered by the addition of a dose of hydrogen and are therefore called hydroxides. Such are the following—†

Potassium		Hydrogen		Oxygen		Caustic Potash
39	+	1	+	16	=	56
Sodium		Hydrogen		Oxygen		Caustic Soda
23	+	1	+	16	=	40

These metals, potassium and sodium, have been obtained by very ingenious methods; they are very difficult to obtain in a separate form, and have a tendency (in some cases so intense as to

* 'Calcium Hydroxide.' Fownes and Watts, vol. i. p. 168.
† Johnson, 'How Crops Grow,' pp. 124–127.

cause a sort of explosion) to return to the compound state by reunion with oxygen. This can be shown by a beautiful experiment with potassium, which appears to take fire when thrown upon water because it takes the oxygen from the water and causes heat, so intense that the hydrogen burns.*

WHAT IS THE USE OF ANALYSIS.

It may occur to you to ask what is the use of all this reduction of compounds to these elements? If these elementary metals are so difficult to present in a separate form, and if they have such a tendency to go back into their former compounds, what is the practical application of this knowledge to Agriculture? I might answer generally, that it is only by an accurate knowledge of the substances we are dealing with, and by learning how they are affected by the circumstances with which we have to deal, such as moisture, heat, chemical affinity, &c., that we can hope to increase our power of cultivating plants and feeding animals with a view to profit. And surely every one must feel the intense interest involved in the question, What is this thing or that thing made of? especially when we find that a few elements of matter build up all the forms of life and beauty around us.

But the more immediate purpose now in hand is

* Roscoe's 'Primer,' Art. 58, p. 98.

to enable young students to attach some clear meaning to the modern language of science.

The scientific books now use the terms calcium and sodium, and potassium; lime and soda, and potash, with which the farmer is familiar, are less used because more precise accuracy is needful in treating of chemical composition and analysis.

Even ammonia is almost superseded now by the name of an imaginary metal, called ammonium, which no one ever saw, but which in all chemical books is now treated like potassium, a metal, in calculation; because some such body seems required by theory to explain the action of ammonia alongside of the other bases or alkalies.

It may be well at this point to mention the practical tests by which acids and bases are distinguishable.

Acids turn vegetable colours to a bright red. Leaves out of little books of litmus paper, to be obtained for a penny at any chemist's shop, are in constant use as tests of acids. They become immediately red when dipped in any liquid which contains a small quantity of acid not combined with a base. The same paper, when faintly reddened by vinegar or any other acid, is a test for an alkali, which, if present uncombined with an acid, immediately restores the blue colour. The alkalies also turn paper tinged yellow with the colouring matter of turmeric to a reddish brown.—Miller's 'Text-book,' page 31.

CHAPTER IV.

CHEMICAL PRINCIPLES.

So far we have dealt with only one of the component parts of salts—namely, the Bases. Before we go on to the acids it will be well to say a few words about chemical laws or principles.

All the statements I have laid before you (if I except the sentence about ammonium) have been absolutely matters of fact, resting on weight and measure; and not in any way depending on speculation or theory.

I may now ask you to bear with me if I endeavour in a plain way to bring together the various figures which I have put before you, so as to lead up to some principles, and then go on to their application.

These principles, which I here clothe loosely in a popular garb, are given in a precise form further on, page 55, on competent authority.

I. Every one of the elements of which I have spoken bears a fixed relation, of number or weight, to hydrogen, which counts as one, see page 45.

II. The same figures also express the relation which each element bears to every other element.

III. No element can enter into combination with any other element unless each element brings to the compound exactly the proportion expressed by the number belonging to it, or the double, or some other multiple.*

Chemical bargains admit of no small change, all the contracts are made in complete sums, that is, not fractions of those sums. If you attempt to combine 20 grains of oxygen with 12 grains of carbon, only 16 of oxygen can enter into combination, the other 4 will be left out. But, if you try the double of 16, then the 32 grains will combine with the 12, and make a different kind of compound.

The first of these compounds is carbonic oxide, 28 grains. The second, carbonic acid, 44 grains. Still using the old-fashioned names.

But now we had better try to fall in with the new style of scientific language, and call these compounds, just referred to in the last sentence, by their new names :—

Carbon		Oxygen		Carbon monoxide
12	+	16	=	28
Carbon		Oxygen		Carbon dioxide.
12	+	32	=	44

* Round numbers only are used in this book; in modern text-books the numbers are more exactly given in decimals.

No doubt you know that "mon" stands for *one*, single, or alone, and "di" stands for *two*, or double.

Chemical Symbols.

Now I will ask you to take a further step in Chemical language.

Each of all these elements of which we have been speaking has its symbol, and the symbol is not only a sort of initial for the "proper name," but it also tells us the "combining proportion"—the four first elements of which we spoke are thus expressed :—

	Symbol.	Combining Number.
Hydrogen	H	1
Oxygen	O	16
Carbon	C	12
Nitrogen	N	14

Each letter stands both for the name and number on the same line.

If there is in a compound a double dose, it is expressed thus, H_2; if a triple dose thus, H_3.* So we have—

Water (H H O) = 1 + 1 + 16 .. .. = H_2O = 18
Carbon dioxide (C O O) = 12 + 16 + 16 = CO_2 = 44
Ammonia (N H H H) = 14 + 1 + 1 + 1 = NH_3 = 17

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* It may be well to explain to those of my young readers who have learned a little algebra at school, that there is no multiplication between these capital letters. H O does not

The following are the symbols for the elements with which we are chiefly concerned in Agriculture. They may be arranged under two heads :—

Non-Metals.			*Metals.*		
Hydrogen ..	H	1	Calcium	Ca	40
Oxygen ..	O	16	Potassium (Kali)	K	39
Nitrogen ..	N	14	Sodium (Natron)	Na	23
Carbon	C	12	Magnesium ..	Mg	24
			Iron, Ferrum ..	Fe	56
Phosphorus ..	P	31			
Sulphur ..	S	32			
Chlorine ..	Cl	35·5			
Silicon	Si	28			

There is in these two lists no attempt to arrange the elements with reference to any chemical theory, they are placed rather in the order of their importance to the farmer.

It may, however, be well to mention at this point that, *besides the combining numbers* given above, there is a classification of these elements which has great importance in modern science. Some elements can only take into union a single dose of any other, though they may themselves be

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mean "$(h \times o)$," but $(h+o)$, or rather, H combined with O. H_2 does not mean $(h \times h) = h^2$, nor does H_3 mean $(h \times h^2) = h^3$; we have no squares and cubes. But such a formula as $2(H_2O)$ means *twice* $(H+H+O)$, equal therefore to $(H+H+H+H+O+O)$ or $(4H+2O)$ the number 2 or 3 multiplying a group of letters, separated by a comma from others, which group generally means a compound called a molecule. For the meaning of the word "molecule," see page 56.

doubled, or trebled. Hydrogen, for instance, as we have seen, is united with oxygen in a double dose to form water, in a triple dose with nitrogen to form ammonia. But hydrogen does not take into union a double dose of any other element; neither does chlorine. So one dose of hydrogen and one dose of chlorine make what I may call a monogamous (one man one wife) union, and neither can enter into polygamy (or plurality of husband or wife). Oxygen can take two doses; nitrogen can take three doses (or more); carbon can take four doses.

On this basis of fact is built a large structure of most important theory, called the doctrine of *quantivalence or valency*—meaning how much is each element worth? as in a limited liability company a careful enquiry into the worth or credit of each new partner may be made before he is allowed to take shares. For the present it may suffice to indicate by four samples the types on which an important classification is set out in chemical books even of an elementary character.

$Cl.H.$	$O.H_2$	$N.H_3$	$C.H_4$
Hydrochloric Acid.	Water.	Ammonia.	March gas.
$35 + 1 = 36$	$16 + 2 = 18$	$14 + 3 = 17$	$12 + 4 = 16$

These four compounds illustrate the principle of union with one, two, three, or four doses; but in

fact nitrogen is capable of taking five doses, and so is phosphorus; so what is here stated is far from a complete account of the principle which, in addition to the names given above, is sometimes called the principle of "atomicity."

THREE IMPORTANT ACIDS.

There are two acids which require special notice, because they contain two principal elements of fertility which have to be supplied by the farmer in the Agriculture of the present day.

These two acids are *phosphoric acid* and *nitric acid* (aquafortis). A word must also be said about *sulphuric acid* (oil of vitriol), because, though it is not wanted to supply food for plants (indeed we were told in Sussex that it was poison to them), it is of much importance in cooking phosphoric manure into *superphosphate*, and also in storing ammonia for use as *sulphate of ammonia.*

Moreover, all these acids are now changing their names. It will not be necessary to say much about the modern theories which have led to these changes.

Nitric acid in a pure state consists of two doses of nitrogen, and five doses of oxygen, and these are combined with water. As Johnson says, "it is very remarkable that the union of these two gases so harmless (as a mixture) in the air should produce

the burning and corrosive compound which this acid is known to be." I may add, it is as remarkable that it should be one main principle in producing our most nutritious food. But in this corrosive state it never reaches plants. It is formed from decaying animal or vegetable matter, and is generally present in chemical union with either lime, or potash, or soda, as a salt of nitric acid. Such a salt so united is called a *nitrate.* Unfortunately, for nitrogen is an expensive article, all the nitrates are very soluble, and are easily washed out of the soil through the drains in rainy seasons.

Phosphoric acid consists of two doses of phosphorus with five doses of oxygen, combined with water. This acid also is corrosive. We have to deal with it chiefly in combination with lime, as an essential part of bone and also a necessary ingredient in the seeds of plants. It is a valuable promoter of the early growth of root-crops, and generally beneficial to spring-sown crops, such as barley.*

Sulphuric acid consists of one dose of sulphur and three doses of oxygen, combined with water; but it has an intense thirst for more water, which thirst causes it, in the form of oil of vitriol, to be so burning as to extract the water out of any vegetable or animal substance, leaving it black. Its chief use to the farmer is in dissolving bones or other phosphates, which are not soluble in water.

* See Chapter X.

It will be noticed that I have mentioned in each case the addition of water; and that each of these acids has a large proportion of oxygen; according to modern theory there is no acid without hydrogen. So what used to be called a dry or anhydrous acid is now called, not an acid, but an anhydride.*

Another acid ought to be mentioned, *hydrochloric acid.* It is known to the farmer as *muriatic acid*

* In Johnston and Cameron's 'Agricultural Chemistry and Geology,' the names are given thus:—

Old Name.	*New Name.*
Anhydrous or dry sulphuric acid	Sulphuric anhydride or tri-oxide.
Anhydrous nitric acid ..	Nitric anhydride or dinitric pentoxide.
Anhydrous phosphoric acid	Phosphoric anhydride or di-phosphoric pentoxide.

Acids are now looked on as salts of hydrogen. These acids, in still more advanced modern style, may be often found thus named:—

Sulphuric acid	Hydrogen sulphate.
Nitric acid	Hydrogen nitrate.
Phosphoric acid	Hydrogen phosphate.

See Harcourt and Madan, 'Practical Chemistry.'

Water is considered an oxide of hydrogen. In Jago's 'Text-book' the chapter on water is headed thus:—

"There are two oxides of hydrogen known:

Hydrogen monoxide or water . . . . H_2O
Hydrogen dioxide or hydroxyll . . . $H_2.O_2$."

But these refinements are unnecessary for farmers or their sons who desire only to have some intelligent insight into the composition and practical action of manures and cattle foods, as now explained by science.

in muriate of potash. Also it is frequently referred to in elementary books on account of the simplicity of its composition, one dose of hydrogen and one of chlorine (see above, p. 47). It enters into a number of the simplest experiments, as, for instance, in decomposing lime and causing carbonic acid to escape or effervesce, leaving chloride of calcium (see p. 62).

It may not be out of place at this point to notice the fact that there are other acids about which much has been written; among these are the somewhat obscure acids known as *humic* and *ulmic*, resulting from the decay of vegetable matter in the soil. There is a very general impression among farmers and gardeners that substances of this kind, under the general name of humus, constitute valuable food for plants. The subject was much discussed from the time of Sir H. Davy to that of Liebig.* What Sir John Lawes has taught us will be shown further on.† But as there is no special chemical point involved in the nature of these acids, it is needless to dwell on the subject. As a practical question it is probable that lime has a useful effect in turning these acids to good account. The subject is one deserving further experimental investigation. There is much information on the subject of humus in Johnson, 'How Crops Feed,' chap. v. pp. 224–238.

* See pages 85, 88. † See Chapter X.

PART II.

CHAPTER V.

ORGANIC CHEMISTRY.

WE began with a simple description of substances in common use, which are, however, compounds in a very complex form—the result of life in animals and vegetables.

An attempt was made to point out in popular language the obvious but characteristic differences of those compounds or parts of the animals and vegetables, and of the sources from which they derive their nourishment. We may now express in chemical terms the difference between the constituents of the fatty matter, and those of the flesh-forming matter. The first (fat, and the foods, starch and sugar) consist exclusively of carbon and the elements of water (not exactly water, but its two elements). The fleshy parts and their food contain in addition to the constituents of fat, also nitrogen, and a small quantity of sulphur and phosphorus.

We have been trying in a very general way to enquire how such compounds as are called salts, and some others, can be, and are, divided into parts, quite

opposite in their properties, especially as regards acidity and alkalinity, or the opposite of acidity.

We then made acquaintance with compounds of a simpler character, consisting generally of only two elements, and we found that they could be reduced to simpler elements still, some of which are called metals, and some non-metals.

Having thus pulled our old house to pieces and arranged the building materials in certain groups, we may proceed to build up the living *organisms*, as plants and animals are called. All that we have been speaking about hitherto is called *inorganic chemistry*, that is to say, we have dealt with the gases, acids, bases, and metals found in the mineral kingdom, merely as regards their quantities and proportions and compounds.

But plants have roots and stems, and leaves and flowers, and seeds. Animals have limbs, and organs of digestion, circulation and respiration, muscles and tendons, to say nothing of nerve and brain. These are *organs*, so there is a branch of chemistry most practical, as dealing with all that we eat and drink, with our blood and its various secretions, and also with drugs and medicines, and with many branches of manufactures. This branch of chemistry has long been called, and is still generally known as, *Organic Chemistry*.

For a long time it was believed that the compounds discovered (and separately defined) in

animals and vegetables could be produced only by living structures. "A large number of organic compounds can now be obtained artificially, without the aid of a living organism. . . . Another definition or additional definition of organic chemistry, or the chemistry of animate nature (the laws of which do not differ from those of inanimate nature), is now generally adopted, namely, the *chemistry of carbon compounds.*" *

General Principles.

Before we enquire into any of the results of organic chemistry, which bear on Agriculture, it may be desirable to take notice of two theoretical or speculative doctrines, which may be said to be the keys to the modern science of chemistry, but the next six pages may be passed over by any reader who does not care to think about the theoretical explanation which chemists have sought for the facts of their science.

Atomic Theory.

We have dwelt already at several points on the essential principle, or universal fact, that all

* The quotation in the text is taken from 'Chemistry, General, Medical, and Pharmaceutical,' by Professor Atfield, p. 457. I have derived much assistance from the lucid and practical explanations in this book. It is probably in the hands of the Pharmaceutical Chemists in every market town.

compounds consist of certain elements in definite proportions both to hydrogen, as the unit, and to one another. The first theory endeavours to account for this fact by the supposition that all the elements are composed of particles so small that they cannot be seen, and cannot be divided. Though their *actual* weights must be entirely beyond the reach of any method of weighing, it is assumed that their *relative* weights can be known. These particles, or material units, are called *atoms*. For example, an atom of oxygen is supposed to be sixteen times as heavy as an atom of hydrogen. This is called the Atomic Theory of Dalton (1801). But it is important to notice the fact that the smallest atoms combine in molecules or groups, as stated at pages 57 and 58; this is fact, not mere theory.

I subjoin a clear scientific statement of these laws of chemical combination, taken from a manual of Practical Chemistry, by Mr. Vernon Harcourt, F.R.S., Lee's Reader, Christ Church, Oxford, and Mr. Madan, F.C.S., formerly Science Master, Eton College, 4th Ed., 1887.*

I.—*Law of Constant Proportion.*—A particular compound always consists of the same elements united in the same proportion.

II.—*Law of Multiple Proportion.*—When one body combines with another in more than one

* 'Modern Practical Chemistry,' Appendix B, p. 566.

proportion, the higher proportions are multiples of the lowest.

III.—*Law of Reciprocal Proportion.*—If two bodies, A and B, combine with a third body, C., they can only combine with each other in proportions which are measures or multiples of the proportions in which they combine with C.

IV.—*Law of Compound Proportion.*—The proportion in which a compound unites with anything else is the sum or multiple of the sum of the proportions in which its elements are present in it.

The above laws are simply the expression of facts observed in experimental work; they exist quite independently of any speculation as to their cause.

Molecular Theory.

There is another theory of more recent date, still more important, if true, and more difficult to understand. I have kept it so far carefully out of sight, though in some books which have had great success as text-books for examinations, the most complex problems and the most elaborate scientific phraseology are put forward as infallible truth at the very outset. I can only imagine that such books are committed to memory with little benefit to the learners in an educational sense.

I can hardly venture to explain these theories in popular language of my own. It is many years

since I had some practice in a laboratory, and such practice is needed to keep up with modern methods and explanations of facts. I regard with simple amazement the amount of industrious work that has been done during the last fifty years in our own country and on the Continent.

I think that the best course I can now take will be to quote a few short statements of principle from elementary works written by teachers of acknowledged authority, before I attempt to show how the chemical knowledge of the present day bears on the production of crops and the feeding of animals.

Professor Crum Brown, of the University of Edinburgh, in his 'Elementary Manual,' says: "When we use the words water, common salt, or potassium sulphate, we do not indicate any particular quantities of those bodies; but when we write H_2O, $NaCl$, or K_2SO_4, we mean 18 parts of water, 58·5 parts of common salt, or 174 parts of sulphate of potash."

"Just as the quantity of an element represented by its symbol" [one capital letter] "is called its atomic weight, so the quantity of a substance" [or compound of elements] "represented by its formula" [more than one letter, or one letter doubled] "is called its molecular weight."—§ 48, p. 45.

"The Molecular theory supposes that when combination takes place the atoms of the constituents go together to form groups or mole-

cules. . . . The formula of a compound may thus be considered as a list of the number and kind of atoms forming the molecule of the compound."—§ 52, p. 47.

Professor Reynolds, of the University of Dublin, in his 'Experimental Chemistry for Junior Students,' Part I., 4th Ed. 1887, says: "The study of the composition of water has made known the curious fact that a certain volume of oxygen requires twice its volume of hydrogen to form water," and "therefore the two gases unite in a definite proportion by volume as well as by weight."—Chap. V. p. 44.

The same thing is further expressed in the following statement: "One molecule of oxygen unites with two molecules of hydrogen to form the compound water."—p. 49.

Then follows a clear description of an experiment, which leads to the conclusion that "one molecule of water-gas occupies the same volume as one molecule of hydrogen," and that "one molecule of water-gas must have the relative weight ·18 . . . referred to the hydrogen molecule 2."—p. 53.

The following definitions are added.

"1. *A molecule* of an element or compound is the smallest portion of a body that can exist *in a free state.*

"2. *An atom* of a chemical element is the smallest portion of it that can take part in a *chemical*

change, and is almost always half the *gaseous* molecule."

Johnson, 'How Crops Grow,' p. 48, says:

"*Molecular weights of compounds.*—While elements unite by *indivisible atoms* to form compounds, the compounds themselves combine with each other, or exist as *Molecules*, or *aggregations of atoms.* It has indeed been customary to speak of *atoms of a compound body*; but this is an absurdity, for the smallest particles of compounds admit of separation into their elements. The term *Molecule* implies capacity for division, just as *atom* excludes that idea. The molecular weight of a compound is the sum of the weights of the atoms which compose it.

"The following scheme illustrates the molecular composition of a somewhat complex compound, one of the carbonates of ammonia.

"Ammonia gas results from the union of one atom of nitrogen with three atoms of hydrogen, NH_3. One molecule of ammonia gas unites with a molecule of carbonic acid gas, CO_2, and a molecule of water, H_2O, to produce a *molecule* of carbonate of ammonia."

Carbonate of Ammonia 1 mol.	Ammonia 1 mol.	Hydrogen	3	= 17 parts	79 parts.
		Nitrogen	14		
	Carbonic acid 1 mol.	Carbon	12	= 44 parts	
		Oxygen	32		
	Water 1 mol.	Hydrogen	2	= 18 parts	
		Oxygen	16		

The molecular weight of carbonate of ammonia is therefore 79.

This may be taken to be *a fact apart from any theory.*

There are several ways of stating the contents of a compound. One is to give the *percentage* of each element, as, for instance, 100 parts of water may be stated to contain

88·88 per cent. of oxygen.
11·11 per cent. of hydrogen.

This we shall have to employ further on, in the case of several vegetable and animal compounds, the chemical formulæ of which cannot be yet clearly made out.* But we must try to learn the use of formulæ, which really are very helpful both to the understanding and the memory.

* It will be worth the reader's while, if he has had patience enough to read the last few pages, to read Article 42, pp. 190–198, in Miller's 'Text-book,' on the Atomic Theory and the Molecular Theory, from which the following passage is extracted:—

"The term *molecular volume* is used to signify the space occupied by a molecule of the body in the form of gas or vapour compared with that of the atom of hydrogen, or the *atomic volume* of hydrogen. Now the volume of the *molecule* of a compound body in the aeriform state $\boxed{\;\;\vdots\;\;}$ is exactly double the volume of the *atom* of hydrogen."

See also p. 63 for an illustration of how two atoms of hydrogen united with one atom of oxygen (three atoms) form only two volumes of water:—

$$\boxed{\mathrm{H} \vdots \mathrm{H}} + \boxed{\mathrm{O}} = \boxed{\mathrm{H_2O}}.$$

CHAPTER VI.

CHEMICAL FORMULÆ.—EMPIRICAL AND RATIONAL.

THERE are two kinds of formulæ for stating the contents of compounds more complex than water. *Carbonate of ammonia* may be stated to contain, as ascertained by experiment—

		Parts.
1 proportion of	Nitrogen	14
1 " "	Carbon	12
3 proportions of	Oxygen	48
5 " "	Hydrogen	5
		79

These several parts and their quantities per cent. being ascertained by analysis to be contained in the compound as a *matter of fact*, this fact is expressed by chemists in what is called an *empirical* formula, NCO_3H_5.

But there is another kind of formula which professes to give the *molecules*, or inner groups, of the several combinations which enter into the whole—namely, carbon dioxide (carbonic acid), ammonia, and water, thus—

Ammonia	Water	Carbonic Acid
NH_3	H_2O	CO_2

"This combination is expressed in what is called a *rational formula*, NH_3,H_2O,CO_2. A substance may have as many rational formulæ as there are rational modes of viewing its constitution.

I state this as it is given in Johnson's 'How Crops Grow,' because it deals in a simple form with elements and compounds of which we have already been speaking. But I apprehend that this mode of statement is not in accordance with the present state of theory. In modern books we find carbonate of ammonia called *Ammonium carbonate*, and expressed in a rational formula as $(H_4N)HCO_3$.*

Carbonate of ammonia has been thus dwelt on, not only because it is convenient as an illustration, but because it has a twofold importance for the farmer.

1. It contains the two gases from which plants obtain their food.

2. It is present in the gas which so often escapes from ill-managed dung-heaps.

Professor Miller's illustration of chemical formulæ and chemical equations (introduced early in his 'Text-book') seems to me especially instructive. He takes a piece of marble, which used to be called carbonate of lime (CO_2 of CaO), now called calcic carbonate ($CaCO_3$) and treats it with some hydro-

* A fuller title is given in Fownes and Watts' 'Inorganic Chemistry,' p. 394. Ammonium and hydrogen carbonate, or Mono-ammonic Carbonate $(NH_4)HCO_3$, commonly called Bicarbonate of Ammonia.

chloric acid (HCl), and gives the chemical equation as follows :

$$CaCO_3 + 2\ HCl = CaCl_2 + H_2O + CO_2.$$

He points out that the sign = does not indicate "absolute equality" or "identity," but rather is employed in the sense of the word "yields." If certain compounds on the left hand are properly mixed, a chemical change will take place, yielding the compounds on the right hand of the sign =. He explains in words the meaning of the above equation thus :—

"Mix 100 grams of marble with a solution of 73 grams of hydrochloric acid : it will yield 111 grams of calcic chloride," [Chloride of calcium] "18 grams of water, and 44 grams of carbonic anhydride" [carbonic acid].

$$\begin{array}{ccccccc} \text{Calcic Carbonate.} & \text{Hydrochloric Acid.} & & \text{Calcic Chloride.} & \text{Water.} & \text{Carbonic Anhydride.} \\ CaCO_3. & +2\ HCl. & & CaCl_2. & H_2O. & CO_2. \end{array}$$

$$\underbrace{\underbrace{40+12+(16\times3)}_{100}\quad \underbrace{2(1+35\cdot5)}_{73}}_{173} = \underbrace{\underbrace{40+(35\cdot5\times2)}_{111}\quad \underbrace{(1\times2)+16}_{18}\quad \underbrace{12+(16\times2)}_{44}}_{173}$$

Organic Compounds.

We may now proceed to state in a plain way what are the compounds of which plants and animals are made up ; and to give some hints as to the changes which take place in these living organisms, as they grow from their birth to maturity, and as they decay till life is extinct ; and further,

as to the changes which take place in the decayed matter available as plant food or manure.

As I approach this part of my subject I have turned to 'The Chemistry of the Farm,' by R. Warington, F.R.S., Rothamsted.

In page 2 occurs the following admirable summary :—

"The combustible part of plants is made up of five chemical elements—carbon, oxygen, hydrogen, nitrogen, and sulphur. Carbon generally forms about one-half of the dry combustible matter of plants. Nitrogen seldom exceeds 4 per cent. of the dry matter, and is generally present in much smaller amount. Sulphur is still smaller in quantity. The remainder is oxygen and hydrogen."

"The carbon, hydrogen, and oxygen form the cellulose, lignose, pectin, starch, sugar, fat, and vegetable acids which plants contain. The same elements united with nitrogen form the *amides* and *alkaloids*, and, further united with sulphur, the still more important *albuminoids*, which are essential constituents of all plants."

Mr. Warington goes on to name the elements potassium, magnesium, calcium, and iron (the last in very small quantities), as present in all plants. He points out that these metals occur in the plant as salts, combined with phosphoric, nitric, sulphuric, and various vegetable acids, phosphates, sulphates, nitrates, and carbonates.

The two passages which I have quoted verbatim are what we may call clean grit, condensed like Liebig's food. Every word is well weighed, and has a perfectly lucid meaning based on fact.

I may, perhaps, express the hope that, in what I have already written, I may have done something to help my young friends to assimilate the food in the first paragraph. In what I have to say further, I shall endeavour to help the reader to digest the contents of the second paragraph, which contains a few rather tough morsels.

It is with great satisfaction that I notice what Mr. Warington says in his preface, that Mr. Johnson's 'How Crops Grow,' and 'How Crops Feed,' are excellent books. I have used them both in what I have already written, and proceed to do so more fully.

We are now to consider what are the *organic compounds* to be found in plants. Mr. Johnson says that they may be conveniently called "proximate elements," a phrase often used in contradistinction to "ultimate elements," which admit of no further subdivision or analysis. I do not think the expression proximate element a convenient one, and shall avoid it. We are dealing essentially with compounds in living structures or organisms, built up or developed out of elements, and these compounds are liable to many changes.

Two Classes of Organic Compounds.

We must first draw a broad distinction between two classes of compounds, to which we may now give the names by which they are usually distinguished in chemistry, non-nitrogenous and nitrogenous.*

The *non-nitrogenous* class is that headed by the letter A in the table on p. 11. *Starch* in the plant, *Fat* in the animal, may be taken as the types of this class.

The *nitrogenous* class is that headed by the letter E in the same table. *Gluten* or *albumen* in the plant, *flesh* in the animal, may stand as the types of this class.

Each of these classes includes several subdivisions.

It is desirable, however, for agricultural purposes to adopt the usual classification under three heads :—Carbohydrates, Fats and Oils, and Albuminoids. The two first are non-nitrogenous, the third are Nitrogenous.

* The great advance in the theory of nutrition was made by Liebig, who laid the foundation of our present knowledge of the subject. According to Liebig, foods may be divided into two classes; the plastic, for the construction of the organism, and the respiratory, for the maintenance of the temperature. To the former class he referred the albuminates or proteids; to the latter, the carbohydrates and fats.—Landois and Stirling's 'Text-book on Human Physiology,' p. 478.

CHAPTER VII.

CONSTITUENTS OF FOOD.—CARBOHYDRATES AND FATS.

In the non-nitrogenous class we may first take the subdivision of which starch is suggested as the special vegetable type. There are several groups under this head. They all agree in this, that they are composed of carbon united to hydrogen and oxygen *in the proportion which forms water*; they are therefore called carbohydrates.

"The bodies of this subdivision form by far the larger share, perhaps seven-eighths, of all the *dry matter* of vegetables, and most of them are distributed throughout all parts of plants." *

The following may be taken as the principal compounds in this subdivision. *Cellulose* (which is almost identical in composition with *starch*) and *sugar*; of sugar there are two, if not three, kinds, cane-sugar, grape-sugar, and fruit-sugar.

Plants consist of cells visible only with a microscope. By the increase of these cells plants grow. The outer case at least of these cells is composed

* Johnson, 'How Crops Grow,' p. 55.

of a matter (in which there is no nitrogen) which gives to the substance the name *cellulose.*

"But the most important and, next to water and cellulose, the most abundant ingredient of agricultural plants, is *starch.*" * It abounds in wheat, rye, barley, rice, and potatoes. Under great heat it changes into a substance called *dextrin*, as in the case of baking. Starch also changes under the influence of fermentation, of which malting for brewing is an example. It is not very digestible unless it has been well cooked, or until it has been mixed with saliva; it is unfit for the food of infants before they have teeth, because saliva turns it into sugar, which is more digestible; and this saliva young infants have not in their mouths.

To the stock-feeder starch must always be an important, if not the most important, constituent of the food for cattle, *but it has no effect as manure.*

The composition of starch and sugar is thus shown by the percentage of carbon, hydrogen, and oxygen:—

Cellulose or Starch.		Cane Sugar.		Grape Sugar.	
Carbon ..	44·44	Carbon ..	42·11	Carbon ..	40·00
Hydrogen	6·17	Hydrogen	6·43	Hydrogen	6·67
Oxygen ..	49·39	Oxygen ..	51·46	Oxygen ..	53·33

By a neat arithmetical calculation † (which, as

* Johnson, p. 66.

† The principle of this calculation is explained and worked out in Jago's 'Elementary Text-book,' p. 101.

this is not an educational paper for schoolboys, might be tedious to the reader), the following formulæ are deduced :—

Starch.	Cane Sugar.	Grape Sugar.
C_{12} H_{20} O_{10}	C_{12} H_{22} O_{11}	C_{12} H_{24} O_{12}
$144 + 20 + 160 = 324$	$144 + 22 + 176 = 342$	$144 + 24 + 192 = 360.$

It will be observed that in each case the numbers of parts or atoms by weight under H and O, in the line below the formula, are in the proportion of 1 to 8, which at the outset we found to be the constitution of water; whereas the small number attached to H is in each case the double of the number attached to O—in accordance with the formula for water, H_2O—showing the number of doses or combining atoms.

Starch changes into sugar, as already noticed, by mixture with the saliva in the mouth; the change being shown by an additional molecule of water. Some such change continually goes on in the plant in many cases, as it ripens and forms sugar. The cellulose of young and succulent stems, leaves, and fruits is to a large extent digestible, especially in the stomachs or intestines of animals which feed on herbage, and therefore cellulose ranks among the nutritive substances.* The substances of this group are called *carbo-hydrates*, because they have in their composition either water, or the elements of water in their fixed proportion.

* Johnson, p. 59.

Fats and Oils.

This is a group of organic compounds of especial interest to the farmers. Some oily matters are to be found in nearly all plants; but especially in certain seeds, as hemp, flax, cotton, colza, and olives. Cereal grains, especially oats and maize, contain oil.

All natural fats are mixtures of simple fats, such as stearine, olein, and margarine, which has attracted so much attention lately. The chemistry of fatty matters appears to be complicated. They are compounds of fatty acids with a base named glycerine.

Dr. Pavy, in his work on 'Food,' p. 81, speaking of fats, says:—

"These principles constitute compounds of carbon and hydrogen combined with only a small proportion of oxygen. Represented in round numbers, the following may be given as the percentage composition of the chief fatty principles:—

Carbon	79
Hydrogen	11
Oxygen	10"

Some years ago fats were called *hydro-carbons.* In recent works the term hydro-carbon is restricted to substances composed only of hydrogen and

carbon, such as paraffin, but the difference between the fatty foods and the carbo-hydrates should not be overlooked.

The important point to notice in the fats is the small quantity of oxygen in proportion to hydrogen—10 instead of 88, which would be its proportion in water; therefore the *fatty matters* easily lend themselves to combustion by union with oxygen, and so keep up the warmth of the animal body.

There is a group of bodies including *pectose* and *pectin*, the chemistry of which seems uncertain. They are chiefly to be found in the roots of turnips and beetroots and carrots, also in cabbage. These bodies are important in the kitchen, as changes in the ripening and keeping qualities of fruits, and also in the cooking of vegetables, are caused by the transformation of this group of compounds. It is not improbable that the ripening of mangel-wurzels and the formation of sugar in the store-heaps is due to the transformation of these bodies.

There are also a number of *vegetable acids* which chemists have carefully studied, such as malic acid in most common fruits, tartaric acid in the grape, citric acid in lemons and oranges.* Some bear on the art of making wine, but they are perhaps more

* Johnson, p. 89.

interesting in other industries than that of the farmer.

We must not, however, leave these compounds without reminding the West Country cider-maker that the whole subject of fermentation is deserving of most careful study. Speaking generally, it may be said that, when fermentation is set up, a portion of sugar is decomposed into two molecules, one of alcohol, the other of carbon dioxide.

Alcoholic drinks vary much in strength. Cider, and good beer, 4 to 6 per cent. of neat alcohol; good light wines, 10 to 12 per cent.; sherry and port, fortified, 16 to 18 per cent.; proof spirit, 49¼ per cent.; gin, brandy, &c., vary from 35 degrees below proof to 10 degrees over proof.

CHAPTER VIII.

ALBUMINOIDS.

We may now pass on to the nitrogenous class of compounds with which the vegetable and animal world are both connected. These bodies belong to the second class, distinguished on p. 66 as the *flesh* type; they differ from those to which our attention has hitherto been given because they contain a considerable proportion of nitrogen.

Mr. Lloyd, in his Lectures, thus opens his account of this class :—

"The nitrogen of plants, so far as it affects their nutritive quality, exists as vegetable albumen, or, more properly speaking, as an albuminous compound. Albuminous compounds were formerly called *proteids*, and are now generally spoken of as *albuminoids*."

This last word is one of constant occurrence in scientific writings about Agriculture, and in the advertisements and analyses of various kinds of cattle food. It relates to what is of the utmost importance to the farmer, namely, the nutritious character of food. If I may be excused for

speaking somewhat loosely, to avoid nice technical distinctions, there is a substantial agreement between the glutinous part of wheat flour, the curd or cheesy part of milk, and the flesh of animals; they are all characterized by the presence of a chemical compound which takes its name from albumen, the white of eggs.

The proportions of the different elements in albumen and albuminoids do not seem at present to admit of precise definition in a formula. Their percentage composition is said to vary between the following limits:—

Carbon	52·7	to	54·5
Hydrogen	6·9	„	7·8
Nitrogen	15·4	„	16·5
Oxygen	20·9	„	23·5
Sulphur	0·8	„	1·6

The important point to notice is that all these bodies contain about 16 per cent. of nitrogen, an element which is essential to the formation of flesh.

AMIDES.

There is another word which requires special remark, because it is frequently introduced into writings which treat of the food of animals. The word *amide* occurs frequently in Mr. Warington's admirable 'Handbook,' also in Professor Brown's 'Animal Life,' but I speak feelingly when I say it

is rather hard to have a word so technical used without explanation. The abstract or chemical definition is plain enough.

To go back to old days; Dr. Daubeny, 1850, in his remarkable Introduction to the Atomic theory, thus defines "Amidogen, the name for that hypothetical compound of H_2N which is supposed to produce an amide. An amide is an hypothetical compound consisting of two ingredients, one of which is constituted of the elements of ammonia with one of its atoms of hydrogen removed."

Stockhardt, 1852, in his 'Experimental Chemistry,' p. 213, says:—

"A compound of one atom of nitrogen with two atoms of hydrogen, NH_2, has been called an amide."

Johnson, 'How Crops Feed,' p. 277, says:—

"Nearly every organic acid known has one or several amides. . . . Also urea, the principal solid ingredient of human urine, is an amide of carbonic acid. . . . Thein, the active principle of tea and coffee, and theobromine, that of chocolate, are all regarded as amides."

Perhaps I ought not to have said that the chemical definition of an amide is plain enough. But I have good authority for giving the following explanation. An amide is a compound that may be explained by supposing ammonia to exchange one of its three doses of hydrogen for another

G 2

molecule, generally speaking one of the kind called an acid radicle.

This, however, may be stated * as ascertained fact, that the food which we and the grass-eating animals eat, and which, when we eat it, contains albumen, becomes altered in the process of digestion, and is voided as urea, a compound of nitrogen, which has not the three atoms of hydrogen required for ammonia but only two, and may therefore be called an amide. Such amides are found in various parts and secretions of the body. This urea, by taking up water, returns to the state of ammonia in the compound carbonate of ammonia.

The function of the plant is opposite to that of the digestion and excretion of the animal. Nitrogen, which in the form of ammonia or of nitrates is supplied to the vegetable, gradually builds up, especially in the ripe seed, the nutritious albuminoid. But the plant in building up these albuminoids first changes ammonia into amides, which, though imperfect food for animals, are specially adapted for the gradual development of the plant. If the plant be cut before the grain is ripe, before the albumen is fully formed, there will be a large proportion of amides; in the early stages of growth there is but little albumen found.

* I am indebted to two friends for these explanations of the practical meaning of amide.

The grass of a meadow contains a large proportion of amides. In potatoes, swedes, and mangels, from 40 to 50 per cent. of the nitrogen remains unconverted into albumen. In wheat, oats, and seeds generally, and in linseed cake, and similar compounds, the amount of nitrogen not converted into albumen is generally less than 10 per cent. of the whole.

I think enough has been said under this head,—as to the progressive steps by which the vegetable builds up the materials it derives from the soil and the air, and brings them together to form nutritive food, and as to the complex processes by which these substances build up the animal, and are again degraded into the various excreta,—to show how very important the subject is, and how much we have to learn as to the nutritive value of foods in their different stages of development.

Albuminoid Ratio.

There is another term frequently used in scientific books treating of the food of animals, viz., *albuminoid ratio.* It refers to a point of the utmost importance to the breeder and grazier. The term *nutritive ratio* is sometimes used as equivalent to albuminoid ratio.

It is clear that the carbohydrates (starch, &c.), fatty matter, and albuminoids (flesh-forming or

nitrogenous matters) should all be present in food. Can we ascertain accurately the proportion which the albuminoids or nitrogenous food should bear to the non-nitrogenous or carbonaceous food? It has been suggested that young animals should have one-fifth of their food albuminous, that is, that the albuminoid ratio should be as 1 to 4, and in fattening animals much less, say 1 to 6, or 1 to 8. But here again an important point has to be enquired into; how far in giving oily food does the albuminous food act in stimulating the digestive power, and enabling the animal to lay on fat quickly.*

Another point should be borne in mind, how much of the albuminous food is retained in the body of the animal? It is calculated, Mr. Lloyd states, that "practically, only one-ninth of the nitrogen of the food is retained in the body, the remainder finds its way into the manure."† It is voided not so much in the solids as in the liquid urine.

* As to the need for albuminous food to increase the produce of milk and cream, see p. 125.

† Compare what is quoted from the late Dr. Voelcker, in Chapter XI.

CHAPTER IX.

THE SOIL—ITS MECHANICAL AND CHEMICAL PROPERTIES.

It may not improbably strike some of my practical readers that I have said very little about the soil. When we direct attention to our experiments we are always met by the remark, "what suits one soil don't suit another." The remark is very true, no doubt, but not very instructive, unless we know exactly the meaning and reason of each man's experience on his own soil.

Now, I must be frank with the reader. I think we have heard a great deal too much about the chemical analysis of the soil; or, if not too much, at least much that is not practical.

I believe that a knowledge of the *mechanical texture of the soil*, whether stiff, close, or heavy, or, on the other hand, light, gravelly, or sandy, is a matter of at least as much importance as the analysis of its ultimate elements, and more constantly requiring attention. That is one reason why I have ventured previously to call in question what appeared to me in this relation a pedantic

display of chemical terms; calcium, potassium, magnesium, phosphorus, and sulphur and silica, as leading the practical man off on a wrong scent. I am constantly meeting with intelligent young farmers, who fancy that if they could analyse their soils and their crops they would know what manures to buy. I consider this a delusion, partly due to the long lists of chemical names published in certain books professing to be scientific guides. I must, however, admit that it may be worth while to ascertain by analysis, in certain cases, whether a soil is deficient in lime, or potash, or phosphates, if such analyses are conducted by competent chemists who are in touch with practical farming.

If I have not entirely failed in my attempt and purpose, I hope I have succeeded in impressing on the practical reader how very small a portion of the plants he grows comes out of the soil, and how much directly, or indirectly, comes out of the atmosphere. Let me, at the risk of seeming repetition, restate the case.

Water is composed of two elements, which may be separated as gases, or may enter into new compounds, liquid or solid.

One gas (oxygen) enters into combination with carbon, forming carbonic acid (carbon dioxide), and this being absorbed or inhaled through the leaves on their surface, forms half at least of the weight of the plant, that is, of the dry matter after the

water is evaporated. Another gas (hydrogen) unites with nitrogen (one part of the air) and forms ammonia, and this nitrogen finds its way (somehow, we will come to that presently)* into the most important vital part of vegetables and animals. Another combustible element, phosphorus, united with oxygen, forms phosphoric acid, and that again is vital to the existence of all seeds, and to the bones and flesh of all animals. As I have admitted, on some soils the need for addition of lime and potash may be proved by long experience, or by modern experiment. But, all this being admitted, the practical man will say, "Do come to the point, how about the soil? do let us have something solid, and no more about gases and artificials." Well, there are two main points to be considered about the soil; one is *cultivation*; the other is *condition*.

1. *As to cultivation.*—The object of cultivation may be stated shortly. It is above all things to make a good seed bed. That is to get a sufficient depth of soil into such a texture that the seed sown may thrive, by being able to send out its roots in every direction where it can find what it wants, without impediment. The soil may be hard, or it may be cold; it may be clogged with water, or what is called sour; or it may need the admission of the oxygen of the air. One very

* See Chapter X. on the Action of Manures, p. 100.

important point is that in hot weather it should not bake, but be roughened, in order that, by increased radiation of heat, it may be comparatively cool and not parched. All these are matters well known to the good farmer. I believe they require more attention than the chemical constituents of the soil. Another very important element in cultivation is the judicious use in rotation of deep-rooted crops, such as the leguminous plants which bring up nitrogenous substances from below for the use of roots which spread near the surface.

2. Then comes *Condition*. What then is condition? Condition in the first place may mean the result of a long course of good deep cultivation; but the fuller answer will be given presently in the words of Sir John Lawes. Shortly stated, it is an accumulation, and mixture, of a quantity of vegetable matter with the mineral constituents of the earth derived from the subsoil. This vegetable matter is not ready-made plant food; but a storehouse or reserve of dormant matter, which by good cultivation can be brought into an active state available for the food of the plant.

I do not think that I can offer to my agricultural friends any further assistance by way of introduction to the technical language, or general principles of chemical science.

I wish I could flatter myself with the hope that they will find, in what I have endeavoured to put

into a palatable form, the same keen interest as that which I have felt in searching the why and the wherefore of good farming practice in the intensely difficult speculations of modern chemistry. But I hope I may persuade some few readers, that there is something worth learning from books written by competent men of science in touch with practice, and not from books only, but from real practical work at experiments conducted by landowners and occupiers in the open field under the guidance of an educated chemist, who either has some practical knowledge of Agriculture, or at least some respect for the experience of those who have such knowledge.

But before I proceed to show how chemical principles can be applied in the present day it may be interesting and instructive if we shortly review the opinions of thoughtful men in former years, and the gradual development of accurate knowledge as to what plants require, and whence and how they are to obtain the needed supply.

Historical Sketch, from Jethro Tull to Liebig and Lawes.

It was in old times taken for granted that plants derived all their substance *from the soil.* A sufficient supply of water from seasonable showers was of course desired to promote the early bursting of the

seed into a growing plant; and the warmth of sunshine was deemed essential to the ripening and harvesting of the crops. But fertility was supposed to depend on the soil and on its cultivation. In more recent times rotations of crops, such as the four-course system, have been considered necessary to keep the land free from weeds, and certain crops, such as beans and clover directly, and turnips, if consumed on the land, or brought back in the dung cart, were supposed to be preparatory to the corn crops, or generally ameliorating to the condition of the land. Bare fallows on certain lands were deemed necessary, both for getting rid of weeds and for restoring fertility by what was called rest. "*Beans, wheat, fallow,*" was the unquestioned orthodoxy on the heavy clay lands of Somerset when I wrote my report in 1850. Such views are still far from being quite obsolete.

If we look back now about 200 years, Jethro Tull, who was an original enquirer into facts, convinced himself, if not his contemporaries, that the growth of plants depended entirely on the fine division of the particles of the earth, so that the roots might penetrate the surface in search of what they needed. "Fine particles of the earth are the very pabulum on which the plant subsists." He also seems to have distinguished between particles of *pure earth* and particles of *vegetable earth*, which he thought were returned to the earth from the

air in the form of some invisible dust; he went so far as to suppose that these vegetable particles were "no grosser than those on which the colours of bodies depend." They were regarded as "impalpable and viewless particles which had been exhaled from former plants, and when the vapour of the air was condensed they descended again to replenish the pasture of the plants."

In these views of Jethro Tull we may now, as we look back, see some anticipation of modern scientific enquiries by a really original thinker.

In comparatively recent times Mr. Smith, of Lois Weedon, endeavoured to prove that the soil would by tillage alone supply successive corn crops, unaided by manure, without exhausting its natural resources.

At the beginning of the present century Sir Humphry Davy brought the discoveries of Chemistry to bear on Agriculture in his celebrated lectures delivered before the Board of Agriculture from the year 1802 to 1812.

The great advance in the general Science of Agriculture caused by these lectures is well known. They raised Agriculture from mere blind experience to the level of Science in its widest sense; they included "an examination of all the changes of matter in the growth of plants, the comparative value of their produce as food, the constitution of soils, and the manner in which they were

enriched by manure, or rendered fertile by the different processes of cultivation."

I must not take up the time of the reader by enumerating the chemical discoveries as to the composition of the atmosphere, of water, of the soil, or of vegetables which had been made before the time of Davy by Priestley and Cavendish in England, by De Saussure and others on the Continent.

It was the special merit of Davy that he brought home to English landowners and farmers generally the direct bearing of these scientific discoveries on the explanation of their existing practical experiences, and pointed out the path by which further progress was possible. Davy had himself made brilliant and far-reaching discoveries as to the composition of the four principal earthy matters, as he called them, aluminous, calcareous, siliceous and magnesian, or, as for practical purposes we may now speak of clay, chalk, and sandy or gravelly soils. Of Jethro Tull, Davy says, "In his 'Treatise of 'Horse-hoeing Husbandry' he advanced the opinion that minute earthy particles supplied the whole nourishment of the vegetable world; that air and water were chiefly useful in producing those particles from the land, and that manures acted in no other way than in ameliorating the texture of the soil; in short, that their *agency was mechanical.*"

Now the great step taken first by Davy was to

show that *chemical agency* must be studied, if Agricultural practice was to be either explained or improved by Science.

The first point which Davy laid stress upon was the relation between living and growing plants on the one hand, and the decaying or putrefying remains of vegetables and animals on the other. He also directed attention to carbonic acid gas, as formed by combustion, fermentation, and respiration of animals; and to the action of sunshine, enabling vegetables to decompose carbonic acid gas, to absorb carbon, and to give off oxygen, so that the economy of vegetation is made subservient to the general order of Nature. Truly this balance of the action of vegetables evolving an element necessary to the existence of animals, and of animals exhaling a compound necessary as a food of vegetables, is one of those marvellous harmonies which make us look beyond the constitution of Nature to the Providence which ordained it.

But from these general contemplations we must turn to Davy's view of the food of plants, and specially of manures. He combats at once the common supposition that various manures which act in small quantities, act as condiments or stimulants, rendering common food more nutritive; he says it seems more probable that they supply a necessary element of vegetable fibre, and, it may be added, of animal fibre. Here we have the germ of

the doctrine of the inorganic constituents of plants on which Liebig and Lawes have thrown so much light in our own day.

I must not ask the reader to go into further detail as to Davy's practical teaching, nor anticipate the statement of modern science and practice which will follow.

Davy's general principle was that plants lived on *liquid or soluble* food taken up by the roots, whatever further action might be developed in the leaves.

He believed that there was available in the soil ready-made vegetable food, more or less in a state of decomposition, of which the general type is called *humus.* This is called by gardeners mould, especially leaf mould; it is supposed to be much enriched by stable-dung, and increased by the formation of roots underground. It is also known in the form of peat, however barren. This, in fact, is the prevailing idea of many practical men.

It differs from Jethro Tull's view in regarding plant food as *liquid* rather than *solid.* It differs from modern science in attaching more importance to *soluble matter* than to the action of atmospheric compounds, such as *carbon dioxide and ammonia,* which, though capable of being solid or liquid in union with other matters, are specially known in a *gaseous* form.

I hope my imaginary cross-questioner, who asked

in a former page for something solid, will be patient with me. I must now ask him to listen once more to some evidence about "gases and artificials." If he will give me a hearing, I hope to show him that some views about solids (minerals) are more radically subversive of his old-fashioned traditions than the gases.

I therefore now beg the attention of the practical man to the important results of Liebig's great work in Chemistry as modified by the subsequent forty years' work of Sir John Lawes, Dr. Gilbert, and the constant advice to farmers of our late friend Dr. Augustus Voelcker, and his sons and pupils now living. I have no wish to enter again into the famous controversy (more or less needlessly personal) between Liebig and the two first Chemists* just named. I did my best in the year 1856 to state the case fairly in an article in the Bath and West of England Society's Journal, Vol. IV. No one but a chemist by profession is competent to speak of Liebig's wonderful contributions to chemical knowledge and theory. But I am writing now for practical farmers, and I cannot forget the teaching of my great master and friend Philip Pusey, nor the contemptuous tone in which Liebig spoke of him, referring to one passage in the masterly paper which he wrote on the Progress of Agricultural Knowledge, from 1842–1850, in the Journal of the

* **Dr. Voelcker always held the balance even.**

Royal Agricultural Society, and reprinted in the Bath and West Journal, Vol. I. In that paper Mr. Pusey spoke of "Baron Liebig, that eminent philosopher, whose high reputation could not be injured" by any mistake about the component parts of a mineral manure for wheat. But, after discussing several practical questions resulting from Liebig's discoveries, Mr. Pusey says, "Our best authority, Mr. Lawes, has established certainly so much, that of the two active principles in manure, ammonia is specially suited to corn, phosphorus to turnips, and that turnips are *probably* benefited by the woody matter of straw." In another part of the article Mr. Pusey says: "Liebig admits that woody matter, decomposing under a seed, feeds it until it can derive its carbon from the atmosphere." Speaking for himself, Mr. Pusey says, "I am inclined to suspect that carbon, even in small quantities, is a more active principle than we suppose, . . . water, too, containing carbonic acid, has a special effect on grass.

"At present, however, we can only say that the three leading principles of manure are

1. Ammonia.
2. Phosphorus, and probably
3. Carbon." [*See* p. 109.]

Mr. Pusey goes on to say that "Phosphorus is sluggish, Ammonia is volatile, and flies away," and he adds, "to quicken phosphorus, Liebig has

taught us to dissolve bones, a most valuable discovery."

I have quoted these passages because they deal with opinions (right or wrong) which are very commonly held at the present time; and because, considering the time and circumstances under which they were written, they are most creditable to Mr. Pusey's discernment and generous spirit.

I think if we look back (with a view to take stock of our present progress) at the position taken up by great authorities in science on practical agriculture we may see, that Liebig, in his too unqualified statements about the sufficiency of minerals for manure, and the power of plants to gather all their ammonia (or nitrogen in some form) from the air, omitted to allow for the element of time.* A great tree may gather in a century all the nitrogen it wants from the air; but the farmer wants his crop of wheat within the year (turnips, too, in a few months). In both cases the farmer needs a special supply beyond what is *available in the natural soil*, however rich it may be in minerals or dormant nitrogen. On the other hand we Englishmen, following as we thought the

* At the present day, after forty years of research in England, France and Germany, the power of plants to gain nitrogen directly from the air is an undecided question. The present state of the question is fully explained in a Lecture by Professor Gilbert on the question of the Fixation of Free Nitrogen, delivered at Cirencester College in 1890.

lead from Rothamsted, were disposed to speak of ammonia as a specific for wheat, and phosphorus as a specific for turnips. The idea of a *specific*, so far as it was maintained, was not, strictly speaking, correct. But I remember how I searched in vain for any evidence from analysis that turnips took up a large proportion of phosphate; or that wheat contained a large proportion of nitrogen.

The old controversy is now gone by, but I think the points which I have recalled for the use of the rising generation illustrate the progress which science has made in enlightening and improving practice, and may prepare the reader for the clear light thrown on the use of manures by Sir John Lawes in the chapter which follows this. I will only add that science at the present day in England has learnt to pay closer attention to the structure of the roots and other organs of plants, to the seasons during which they make their growth, and to the particular food which seems adapted to them at different seasons of the year, and under various conditions of soil and climate.

The following extract from a paper, written by Professor Maskelyne and reprinted by me in the Bath and West of England Journal, Vol. IV., 1856, page 269, cannot fail to interest the reader, and will show how practical it was possible for an admirer of Liebig to be as far back as 1856.

Professor Maskelyne on Manures for Wheat and Turnips.

"The light which vegetable physiology has already thrown—and which even a cursory glance at the wheat and turnip plants may throw on the subject of their respective proper manures, is interesting, and tends to remove the apparent anomaly which accumulated evidence regarding these manures may seem to present. The tribe to which wheat belongs is peculiarly leafless; the turnip, on the other hand, expands its well-known abundant surface of leaf to the influence of the atmosphere. The leaf is, as it were, the lung of the plant. At its surface the aërial constituents of the nutriment of the plant are in great part imbibed, and in its substance they are decomposed under the influence of the light, at least in so far as the carbonic acid is concerned. The wheat plant consequently, and all those allied immediately to it, can attract and assimilate but little of this gaseous food by means of their leaf; while the turnip, like nearly all its congeners of the Brassicaceæ tribe, in its large expanse of leaf, covers the field with a vast absorbent surface, that imbibes and turns into turnip food the carbonic acid and ammonia of the air which passes over it.

"But examine the underground feeders of the respective plants, and the relations of their food-collecting powers appear reversed. The wheat

plant, with its deeply and widely penetrating roots and root-fibres, seems to forage in as many cubic feet of soil as the turnip root penetrates inches. The latter, with its vast abnormally developed bulb, presents a comparatively small, because a globular, surface in comparison with its solid contents, while the diverging rootlets that extend from it are confined to a space very limited in comparison with that through which the wheat-root ranges. To maintain then, and develop, the peculiarly abnormal condition of the cultivated turnip, what are the necessary conditions? Clearly to give to it, concentrated and in abundance, the food which it requires; and that food will not be carbonic acid or nitrogen, except in so far as they may act as solvents and carriers of other food—these the leaf gathers abundantly. It is the mineral ingredients of its ash—which the soil may not contain in large enough amount—that must be so supplied to it; pre-eminently, therefore, phosphoric acid in many soils—alkalies also, and alkaline chlorides, in many others—lime and sulphuric acid, too, perhaps in some.

"These must be supplied around the plant in immediate proximity to it. Doubtless, also, the roots of the turnip are less vigorous penetrators of mechanically stubborn soils than are the roots of the cereals, and they thrive therefore, by preference, in lighter lands than these. It may happen,

therefore, that a heavy soil, however rich in the appropriate mineral ingredients of the plant, shall yet resist the lateral extension and development of the roots from the bulb, and while bearing noble wheat crops, respond but sluggishly to the farmer's solicitations for a field of turnips. But the wheat plant, to which a spread of leaf is wanting, is compelled in a great degree to fall back on the liquid contents of the soil imbibed by its roots for that supply of nitrogenous and carbonaceous food out of which it is to build at once its albuminous and glutinous, and its ligneous and starchy constituents; and its development in a given time will therefore be dependent on the amount of ammonia which it can so assimilate by its roots. These roots are consequently endowed with an enterprising habit, and with penetrating and searching powers, which we seek in vain in the more helpless unwieldy turnip. They consist of fibres, each of which pierces deep into the soil—and penetrates that soil—literally ransacks it for food on every side. Obviously, therefore, a smaller percentage of phosphates and other minerals in the soil will suffice for the cereals; not that they want much less of these than the turnip, but that they can go further to collect them. Hence, too, manures that have been in the soil for one or two seasons, and have penetrated further down into it than the surface, may fall more within the range of the foraging roots of this tribe of

plants than manures freshly applied, and therefore only mixed with the upper zone of soil—that zone, in short, in which the turnip grows."

It will be seen at once that the statement made by Mr. Maskelyne many years ago, from a practical consideration of the facts involved in the organs of corn and other crops, throws light at the present day on the action of manure.

Geology and the Soil.

It is sometimes said that the Science of Geology is one which should be studied by the farmer. As an old pupil of Dr. Buckland, I should not be disposed to underrate the agricultural interest of Geology. I have also a lively and grateful recollection of an hour's teaching in the Geological Museum kindly given to me by Mr. De la Beche on the bearing of Geology on the Agriculture of Somerset, a county which includes a greater variety of strata than any other.

From the Chalk hills of the Downs near Chard to the Devonian strata above the granite, it includes Greensand, Oolite, Lias, Mountain Limestone, Coal Measures, Old and New Red Sandstone, and the most noteworthy peats and alluvial soils in the island. Such knowledge is valuable to any one taking a general survey of a district. But what does it avail to a farmer born and bred on a

particular soil, which may probably be a drift entirely different from the underlying stratum ?

Mr. De la Beche pointed out to me that on the Devonian formation there are alternate layers, varying from sharp, barren Sandstone, covered with heather or peat, to laminated Shillet, bearing splendid pasture, worth, as I have reason to know, in some parts, more than £4 an acre annually. There is also a large extent of poor Clay, which, owing I believe mainly to its texture, is difficult to deal with either as pasture or as arable land.

The origin of soils, by the action of water and other causes, from the different strata is well shown in the second chapter of Mr. Lloyd's Lectures. Some useful information is given about the analysis of soils, and their chemical composition, in the third chapter. But the physical properties of soils, explained in the fourth chapter, appear to me specially worthy of study. Their *weight*—their *texture* depending on the fineness of the particles —their power of *absorbing moisture* from the air (such as is shown in salt when exposed to the air) which is called *Hygroscopic*—their power of absorbing not only water-vapour but water itself, called *Capillarity* or *Capillary* attraction—the *evaporation* of water depending both on soil texture and plant growth—the retentive character of some soils or *humidity*—the gain or loss of *heat* at the surface, or at different depths—all

these subjects are *mechanical* or *physical* rather than *chemical*, and are well and concisely treated.

Mr. Lloyd draws attention to the chemical properties of soils, on which modern science and careful experiments have thrown much light. All soils in various degrees, according to their texture and composition, have the properties of—(1) absorbing *gases*, (2) of extracting colouring and other matters out of *solution*, (3) of decomposing some salts (*solids*) and retaining ammonia.

Clay soils have great powers of chemical action. The presence of lime in a soil in some proportion is essential to the retaining of phosphoric acid.

The action of the air or atmosphere on the soil underground is a matter of the utmost importance, and also the process called *Nitrification*, by which ammonia is converted into nitric acid.

"Nitric acid, the most important of all chemical compounds to the farmer, though united with lime or potash, is not retained by soils, but passes through them. It is the one, and one only, substance of great value to the plant which the soil appears to have no power to retain."

Much useful information on the subject of "Soils and their Properties" is to be found in one of Bell's Agricultural Series by Dr. Fream, though the use of difficult scientific phraseology is more frequent than is suited to the practical farmer.

In the wonderful little Manual published by the

Agricultural Department of Ontario, called 'The First Principles of Agriculture,' by Mr. Mills, President of Ontario Agricultural College, is a Chapter on the Soil, which is unrivalled for simplicity.

Climate.

The subject of *climate* is in most minds connected with that of soil. I can but shortly refer the reader to a prize essay on the Climate of the British Islands by Mr. Nicholas Whitley, Surveyor of Truro, published in Vol. XI. of the 'Journal' of the Royal Agricultural Society, and reprinted in Vol. I. of the Bath and West of England 'Journal.'

It points to the effect of the Gulf Stream bringing a current of warm water northward and eastward, charged with vapour, which is precipitated by the mountain districts of West Scotland, the Lakes, Wales, Devon, and Cornwall—the result, mild winters and cool summers.

The low eastern coast of the island from Aberdeenshire to the Thames is exposed to keen, dry winds from North Europe—the result, cold winters and hot summers.

"Whilst the dry atmosphere and generally heavy soils of the East of England are adapted to the growth and ripening of wheat, the cool summer and the humid air of the Western coast are better fitted for grass." The whole paper is worthy of careful study.

PART III.

CHAPTER X.

EXPLANATION OF THE ACTION OF MANURES.

THE following Chapter is an attempt to convey to the practical farmer some of the valuable lessons taught by Sir John Lawes some years ago in an address to North Countrymen, whose climate has some points in common with the hill country of the West.* All that has been written in this book may be considered as preparatory to the practical advice contained in this Part III.

Sir John Lawes begins his Paper by a striking application to Agriculture of the great contest, so forcibly illustrated by our celebrated countryman, Darwin, which has been carried on in the animal and vegetable kingdoms :—

"Endless trials, endless failures, carried on generation after generation, have resulted in a

* An article written by Sir J. B. Lawes for the Newcastle Farmers' Club.

system which may be defined as the 'survival of the fittest.'

"This does not in any way imply that changes or improvements are not to be made, but only that, while other systems have failed, the system in general use has stood its ground, and so has become the survivor in the struggle for existence."

The object of the Paper is to "offer some explanation of the practices now in use, and to give scientific reasons for the processes carried on every day in the operations with which farmers have been familiar for a generation." Sir John Lawes proceeds with great modesty to say that he cannot hope to increase in the smallest degree the profits of any one who reads his remarks; he only hopes to throw some light on the reason of operations daily carried on in practice. One main point of his remarks is to draw attention to the dormant and active forms of nitrogen, and especially to the action of nitric acid.

"Nitrogen exists in soils in three combinations: 1, with carbon; 2, with hydrogen; 3, with oxygen. When in combination with carbon, it is almost, if not quite, as insoluble as phosphoric acid."

And it is in this insoluble form that by far the greater part of nitrogen exists in soils. It is derived partly from vegetation which existed long ago, partly from vegetation recently "grown upon

the land," under which head I understand farmyard dung to be included; but the whole of the nitrogen is not in that form.

"Nitrogen in combination with hydrogen" (as we have seen in a previous chapter) "forms ammonia. Ammonia cannot exist, as such, for any length of time in the soil, as it is rapidly converted into nitric acid."

There is a minute action going on underground which tends to separate the nitrogen from the hydrogen and the carbon, and to unite it (the nitrogen) with oxygen. It thus forms nitric acid. "But to effect this, lime must be present in the soil, and the compound so formed is called nitrate of lime."

The following passage from Mr. Warington's 'Chemistry of the Farm,' further explains the underground process, the explanation of which is due to his special investigation.

"A large part of the elements of plant food contained in soils is present in such a condition that the plants are unable to make use of it. A soil may contain many thousand pounds of phosphoric acid or of nitrogen, and yet be in a poor condition; while a small portion of readily available food, as superphosphate or nitrate of sodium [nitrate of soda], may greatly increase the fertility.

"The nitrogen contained in humus is not in a condition to serve as a general plant food; cereal

crops are apparently unable to appropriate it; leguminous crops, however, possibly assimilate some humic matters. By the action of a minute bacterium present in all soils, humus and ammonia are oxidised, and thus nitrogen is converted into nitric acid. Nitrification only takes place in moist soil sufficiently porous to admit air. It is also necessary that some base should be present with which the nitric acid may combine; this condition is usually fulfilled by the presence of carbonate of calcium [ordinary lime]. Nitrification is most active at summer temperatures; it ceases apparently at the freezing-point."

"Salts of nitric acid, a familiar example of which is nitrate of soda, are not only very soluble in water, but they form no insoluble compounds with the soil." . . . they are therefore easily washed out . . . "living vegetation being alone capable of arresting the escape of nitric acid." It has been shown that a high temperature conduces to the rapid formation of nitric acid, and dry weather tends to prevent it from being washed out before the crops can take it up.

TURNIPS—ACTION OF PHOSPHORIC ACID.

It is unnecessary to remind the reader of the principle established by Sir J. Lawes, that nitrogen is of paramount importance to the corn crops; and

that phosphates are required for roots. But in the paper from which I am quoting, he explains the action of both manures with reference to each crop. As regards turnips, they "are sown at a period of the year when the moisture of the soil is at a minimum, and the temperature at a maximum." The seed has at first to live entirely on itself; "compare its size with that of a bean or pea, or even with a grain of corn, and it will be seen at once how helpless, almost hopeless, is its condition. During this early period it sends down some roots into the soil, and produces a leaf or two above ground; but with so minute a seed the growth of the turnip must be limited, and the first appearance of a leaf often renders it a prey to the fly.

"By the time the store of food in the seed is exhausted, no further growth can take place; and unless the root comes in contact with phosphate, it perishes."

But "it would be a great mistake to suppose that because turnips are grown without a direct supply of nitrogen in manures, they are less dependent upon a supply of this substance [nitrogen] than corn crops."

WHEAT.

Sir J. Lawes gives some very important calculations based on the Rothamsted experiments. He has found that at the end of forty years' growth of successive corn crops enough nitric acid has been liberated from the soil, together with what can be obtained from the air, to grow thirteen bushels of wheat per acre; "that we may supply potash, phosphate, or any other manures—provided that they contain no nitrogen; but it is all in vain, they can produce little or no increase in the crop."

But without any change except the addition of "a sufficient quantity of nitrate of soda, or nitrate of lime would be equally effective, he can grow a crop of from 30 to 40 bushels of wheat per acre every year." His calculation is that he can thus increase the produce from 10 bushels of corn and 1000 lbs. of straw, to 20 bushels and 2000 lbs. of straw, or to 30 bushels and 3000 lbs. of straw, according to the amount of nitrate. The total produce carted off being respectively 1600 lbs., 3200 lbs., 4800 lbs.

He says it will be sufficiently accurate "to say that only 6 lbs. of every 100 lbs. are furnished by the soil, while 94 lbs. are furnished by the atmosphere; and of the 6 lbs. furnished by the soil, 5 lbs. consist of minerals, and 1 lb. of nitrogen."

But calling attention to the seasons, he warns us "that in favourable seasons there will be abundance of grain, and in unfavourable seasons very little."

What is Condition?

That is another very important matter in Sir John Lawes's Paper. How is the nitrogen put into the soil to be made available without waste?

This enables us to get an answer to a question to which very hazy answers are often given by valuers and others: What do we mean by "condition"? Sir J. Lawes "deals with a certain class of compounds of carbon with nitrogen. . . . as it is these compounds which constitute what is commonly called 'condition.'" He says: "When purchased foods are consumed upon the farm, but a small portion of the nitrogen they contain is carried off in the increase of the animal; the larger moiety is found in the urine, though two very important parts exist in the solid excrement, one in the form of undigested food, and the other in the indigestible portion of the food."

"The distinction between nitrate or salts of ammonia and cattle foods—that is to say, between nitrogen in combination with oxygen or hydrogen" [nitrate or ammonia] "and nitrogen in combination with carbon" [cattle food, say cake]—is this, "that in the former the nitrogen is at once available

as food for plants, in the other only a portion of the nitrogen is in an active state, while other portions become slowly available after considerable portions of time.

"Nitrates frequently produce overgrowth, more especially in cold or wet seasons, merely from the fact that they are applied all at once, and in consequence are liable to be taken up rapidly by the plant."

Two Objects of Manure.

It seems to follow from these statements that the farmer should, in the application of manure, carefully consider the different objects to be aimed at, and the different kinds of food to be supplied according to the object in view. Is the object to put into the ground what is called a lasting manure, which will supply the wants of all the crops in a rotation of four or more years? or is the object to put into the ground merely what will probably produce a large increase during *the current year in a favourable season?*

It seems clear that for immediate return there must be a considerable amount of nitrogen, whether for roots or for grain, and this in a form immediately available. It seems almost certain that in wet seasons much of this nitrogen, if ready, will be wasted, and that in a cold season there will be but

a slow conversion of the required food from a dormant to an active and available state; but it is not clear that if the nitrates are not immediately available in the first year, they will be available or forthcoming afterwards.

"It frequently happens that the amount of nitric acid liberated from a soil is not sufficient to grow as large a crop of corn as the cultivator desires; he therefore goes into the market to purchase more. Here I may mention that the nitric acid liberated in an ordinary soil is generally in combination with lime, while in the purchased salt it is combined with soda; but the nitrogen, *which is the active element*, is exactly the same in both compounds.

"It will, I fear, be yet some time before practical farmers will clearly recognize this fact. I have reason to think that they look upon nitrate of soda as bearing the same relation to the ordinary manure of the farm, as mustard and pickles do to beef.

"Farmers as a rule describe nitrate of soda as a stimulant . . . perhaps they might give it a worse name than this if the application were followed by a cold, wet summer, and they found that their corn was overgrown and laid."

UNEXHAUSTED FERTILITY.

Sir J. Lawes gives some important information as to the residue of previous manuring on an experimental barley field with heavy doses of dung and of rape-cake, which had gone on for twenty years. For eleven years afterwards the land received no manure. He calls special attention to the fact that the power of the barley to take food from the soil extends over a period of not much more than three months : so that during an autumn and winter there was no vegetation to take up nitric acid, or to evaporate water from the soil ; this last is an important point not thought enough about. The land which, as already stated, had, after receiving dung for twenty years, been unmanured for eleven years, gave a crop of 36 bushels per acre, and in Sir John Lawes's opinion might go on for twenty or thirty years yielding an increase, due to the unexhausted residue of the original application.

He then says : "It is true that in farming operations dung is supplied in very much smaller amounts, but the principle must be the same. CARBON, *which is only another word for vegetable matter alive or dead*, appears to be the only medium by which nitrogen is accumulated in the soil to be again used by living vegetation." Here then we have the answer to the question, What is "condition" ?

There remains another question. At what cost is condition to be obtained, and maintained? It is at least a locking-up of capital.

"Condition is always accompanied by an increase of carbon in the soil."

"I must point out, however, that *it is not from the carbon being of any value as a manure*, but from the fact of its being the conserver of the store of nitrogen which is liberated at all times of the year, but more especially at the time when vegetation is most active and requires it the most.

"It is the rapidity with which an application of nitrate acts, and the overgrowth which often follows in consequence, that has caused its being looked upon as a stimulant, rather than an important element of plant food."

Potash.

Sir John Lawes says only a few words about one important element of growth—potash. "It is far more largely distributed through soils than phosphoric acid, and when grain and animal products are the only articles sold off the farm, the crops generally find all they require in the land, but it is quite otherwise when roots are grown for sale." He says that when potatoes or roots are grown for sale the cultivator generally has access to town manures which furnish enough potash, but if such manure

is not available, potash in some artificial form will be needed.

The information given with respect to the effect of potash on chalk soils in Norfolk and elsewhere, by the experiments of the Norfolk Chamber of Agriculture is very valuable. It is not, however, fully confirmed by the experiments of the Bath and West of England Society on the Chalk lands in the South of England. (See p. 175.)

Pastures.

Sir J. Lawes closes his lecture by a short reference to the importance of pastures and layers, which being green all the year round, are the great conservers of manure.

He says, "It must be borne in mind it is on a bare soil—that is to say, a soil without vegetation—that the greatest waste of nitric acid takes place, not only from the fact of there being no vegetation to arrest the escaping nitric acid, but also (vegetation being the chief agent for the evaporation of water) on the bare soil there will be the largest amount of drainage."

This reference to pastures is interesting to West of England farmers. Among other considerations, it serves to explain the practice of "grassing out," as it is called, for two or three years, sometimes five or six years, in a rotation; it shows the

wisdom of spreading dung on clovers in the autumn. The tendency of nitrates to escape by the drains shows how very important it is to secure every drop of drain-water that can be carried over our water meadows or any grass land.

Summary of Lessons.

I have thus endeavoured to gather from Sir John Lawes's lecture some of its substance. There is much besides on the question of unexhausted fertility which rather concerns out-going tenants than what are called sitting tenants, and touches on some points more or less open to dispute.

I will try to put into few words the lessons which I think practical men may learn, if only in the way of explaining their own practice :—

1. That nitrogen is the most important element in the food of plants, especially for corn, but also for roots.

2. That phosphoric acid is chiefly important for young plants sown in spring or summer which have not time to forage for themselves underground in autumn and winter.

3. That ammonia is changed into nitric acid, and that nitric acid has to be neutralized by lime or other base before the plant can feed on it.

4. That in this state of a neutral and soluble salt

nitrogen is very liable to be washed out, especially during a rainy season.

5. That an accumulation of vegetable matter underground is an important storehouse for nitrogen, and for condition acting gradually.

6. That nitrates are not stimulants, but food for plants. That ready-made vegetable matter underground is not food for plants till it has been decomposed.

7. That probably lime acts not only by the correction or neutralizing of acids, but also by developing the dormant nitrogen.

8. That while it is of the utmost importance to stir and open soils (when they do not specially require compression) in order to admit the action of the air, the long continuance of bare soil without growing vegetation in cold or wet weather causes great waste of nitrates.

Having thus done my best to call attention to the lessons taught at Rothamsted, I hope I shall not be deemed presumptuous if I say that it is not clear to me that on the thin poor soils near the rock on our hill tops there is any great store of nitrogen to be developed. Certainly we have special need to guard against the waste of nitrogen in the wet climate of the West.

But in Chapter XII., page 180, will be found some remarkable evidence of the effect of phosphate on the oat crop, both on thin shallow soils near

Exmoor, and also on cold washed-out clays, between Dartmoor and the Bristol Channel.

Further west, in Cornwall, some good farmers think there is no manure equal to dissolved bones. But that is a form of bone manure which is generally expensive, and often consists in great part of mineral superphosphate, with a small percentage of organic bones. It would be probably more profitable to follow the advice of Pusey, given forty years ago and strongly confirmed by the late Dr. Voelcker, to buy raw bones finely ground, ferment them for two or three months with moisture, turning the heap occasionally, and add soluble superphosphate. That is a cheap and a lasting manure.

NOTE.

Any readers who may be desirous to trace for themselves the progress of the work at Rothamsted will find the means of doing so in a small 8vo. volume, entitled 'Rothamsted Experiments on the growth of Wheat, Barley, and the mixed Herbage of Grass Land,' by Dr. Fream, published by Horace Cox, *Field* Office, Strand, 1888.

CHAPTER XI.

ON FOOD FOR GRAZING, AND FOR THE DAIRY.

An attempt will be made in the following pages to give a practical application to the feeding of animals of what has been written on chemistry. The scientific terms in common use may here be used without further explanation.

There are two questions on which science can help us to judge of the nourishing value of the different kinds of food :—

1. What is there in the food ?
2. How much of it can the animals digest ?

I cannot better serve my farming friends than by advising them to study one of Morton's Handbooks, by Mr. Warington,* and to follow Professor Brown's advice given in another of those Handbooks, 'Animal Life on the Farm,' by carefully studying chapters v., vi., and vii. of that book ; treating of "foods," their "relation to the

* 'Chemistry of the Farm.' A new edition of Mr. Warington's book, revised and enlarged, has been published since this book has been in type, 1891. My references are to the 4th edition, 1888.

requirements of the animal," and "to the manure produced." But with Mr. Warington's book before me as a guide, and in the hope that many of my readers will have it too, I will now draw instruction from an excellent paper on the "Theoretical and Practical Value of Purchased Food, and of its Residue as Manure," by the late Dr. Voelcker, published in the 'Royal Agricultural Society's Journal,' vol. xii. 1876. Though I may not be able to mark many entire sentences with inverted commas, as they may not be copied *verbatim*, the substance of what follows is derived from that paper.

It has already been pointed out that the solid matters in food may be classed under three heads:—

1. Carbo-hydrates (starch, sugar) and fibre.
2. Ready-made fat.
3. Albuminoids (and amides).

1. The *carbo-hydrates* alone could not possibly support life long, nor would the fat avail without some nitrogenous matter in a digestible form. A certain quantity of this carbonaceous food is essential (for farm animals) to maintain the warmth of the body. About half the carbon in the food is consumed by oxidation (that is, union with the oxygen in the air) through the process of respiration. One consequence of this is that slow feeding for the butcher involves a certain loss of

food wasted in breathing and keeping alive, but adding nothing to the weight of meat sold.

"When food rich in starch or sugar is given in larger quantities than is required to support respiration, and to generate animal heat, the excess of the carbo-hydrates is converted into fat, and stored up in the body, provided there be sufficient nitrogenous matter present."

"Cellulose or woody fibre does the same work, *as far as it is digested*, as the starch or sugar."

"The tender cellulose fibre of unripe straw or of hay is certainly assimilated . . . . to a limited extent . . . by herbivorous animals, whilst the hard woody fibre of over-ripe grass or straw is digested less perfectly, and ejected in larger proportions in the dung."

2. *Ready-made fats and oils* are the most expensive, but also the most valuable of all food constituents; they are readily taken up by healthy animals with a certain amount of change.

"The proportion of carbon in fat amounts to about 80 per cent., which is much more than there is in starch or sugar. In round numbers, one part by weight of fat or oil is as valuable a feeding material as two-and-a-half times as much sugar or starch. But besides this direct value as food, fat serves important functions in the processes of digestion and nutrition." Fat certainly possesses high digestive powers.

I remember, speaking here for myself, that I found out forty years ago the digestive value of 1 lb. of oilcake per day given to what were called straw bullocks in the winter at Cloutisham farm, under Dunkerry beacon, and some of my friends in the hills will, I am sure, say that they have found it lately to be true.

Fat thus takes an active part both in the healthy growth of young stock, and in the processes by which other nutritive constituents are converted into butcher's meat.

3. *Nitrogenous substances* in the state of albumen, or albuminoids, are a most valuable class of organic compounds. "They contain about 16 per cent. of nitrogen and small quantities of sulphur or phosphorus, or both, in organic combination: they are absolutely necessary for the formation of the substance of lean flesh.

"Peas, beans, and all leguminous seeds, linseed-, rape-, cotton-, and other oilcakes, are rich in flesh-forming matters or albuminoids. Most cereal grains also contain considerable proportions of such compounds; whilst roots, green produce, straw, chaff, and similar bulky feeding materials, are, comparatively speaking, poor in albuminoids."

Mr. Warington says "the leguminous seeds, as beans, peas, and lentils, are rich in albuminoids, but not in fat. The cereal grains are much poorer in albuminoids, containing only about one-half the

proportion found in leguminous seeds." "Of the common cereals, oats are generally the most nitrogenous, and maize the least. Oats and maize are characterized by containing more fat than the other cereal grains. The special characteristic of other cereal grains is their richness in an easily digested carbo-hydrate—starch." *

It is, however, necessary at this point to utter a word of warning about the scientific analyses of food. It is not enough to know by analysis the elements or even the compounds of which foods consist, unless careful attention is given to the digestible qualities of each constituent.†

It was at one time supposed that increase of weight of meat depended on the increase of the nitrogenous foods. This is a matter to be determined by experience. Careful feeding experiments appear to have proved that the *amount* of nitrogen in the food, whether grass, or grain, or roots, is not the best test of feeding quality. One main point to be considered is *digestibility*.

"The *proportion*, however, of the nitrogen to the

* P. 84, 4th ed.

† "It has been shown during the last few years that a part of the nitrogen of vegetable foods exists not as albuminoids, but as amides, and in some cases as nitrates." (This applies specially to bran, grains, and malt dust rich in nitrogen, but not all usable.)

"In the case of hay, straw, green-fodder silage, the general composition is a less safe guide to the nourishing value."—Warington, p. 82.

other constituents is the most important test of value. When nitrogen or albuminous food is present in too large a quantity, the animal wastes it to get at the non-nitrogenous heat-forming food it requires; and when not enough nitrogenous food is present, he wastes the heat-formers to get at the flesh-formers." For this explanation I am indebted to Mr. Lloyd.

Before we refer further to what Mr. Lloyd has to say on this subject, the following words of Dr. Voelcker on the manurial value of food deserve attention:

"The *manurial value of food* depends mainly on the amount of—1st, nitrogenous matter; 2nd, potash; 3rd, phosphoric acid, which passes through the body into the dung of the animals—practically the whole of the potash and phosphoric acid pass into the dung." The loss of nitrogen which the food sustains in passing through the animal has been estimated variously at from one-tenth to one-sixteenth.

"On the whole, no great mistake will be made if it be assumed that 90 per cent. of the total amount of nitrogen in such concentrated food as oilcake, when given to fattening stock, is recovered in the solid and liquid excrements, presuming that these are collected without loss."

It is further observed that for a given amount of increase produced oxen void more as manure, and

expend more in respiration, &c., than sheep; and sheep very much more than pigs.

Digestibility.

To return to the question of digestibility, Mr. Lloyd has delivered one or two lectures, in which the result of researches recently carried on in Germany is given. He has drawn up some full tables on the subject, from which a few samples may be taken by way of illustration. It must first be noticed that the water in each kind of food is omitted—the dry food is what we have to do with.

	Percentage Composition.				Percentage Digestible.		
	Dry Matter.	Albuminoids.	Carbo-Hydrates.	Fat.	Albuminoids.	Carbo-Hydrates.	Fat.
Barley Meal ..	83·5	10·0	63·9	2·5	58·0	58·9	1·7
Oats	85·7	12·0	55·7	6·0	..	..	..
Bean Meal	82·4	25·5	45·9	1·6	23·0	50·2	1·4
Maize	87·0	10·6	69·7	5·5	9·1	67·1	4·2
Linseed-Cake ..	79·0	29·5	29·9	9·9	24·8	27·5	8·9
Cotton-Cake, Decorticated	81·2	38·8	19·5	13·7	31·0	18·3	12·3
Swedes	12·0	1·3	9·5	0·1	1·3	10·6	0·1
Turnips	7·3	1·1	5·3	0·1	1·1	6·1	0·1
Cabbages	13·7	2·5	8·1	0·7	1·8	8·2	0·4
Hay (Meadow) ..	79·5	9·7	41·4	2·5	5·4	41·0	1·0
Straw, Barley ..	81·6	3·5	36·7	1·4	1·3	40·6	0·5
Straw, Oat	81·7	4·0	36·2	2·0	1·4	40·1	0·7
Straw, Wheat ..	81·1	3·0	36·9	1·2	0·8	35·6	0·4

The first column in the above Table shows the amount of available solid food or dry matter in

each kind of food. The next three columns show what the chemist finds in each food by analysis. The last three columns show what the animal finds. It is a case of "the proof of the pudding." Though in this case the proof is not exactly what the grazier might wish to find in the sale of the beast, yet it is found by a careful analysis of what the animal has ejected as excrement. I confess I should rather like to see the proof of the live weight on the weighbridge, or the dead weight on the scales of the butcher also. But in fact there are valuable materials in the records of experiments at Rothamsted to which I am unable at present to refer.

Mr. Lloyd has also directed attention to another practical point in a lecture on the Economy of Feeding—namely, the careful attention to what he calls a proper *ration*—he refers to a case of a dairy where the cows were costing 10*s*. 6*d*. a week in the winter. The food was given in too great quantity, and it was not of the quality suitable to a dairy cow. The food was changed, less was given, but of the right sort. The milk came more abundantly and of better quality, and the cost was reduced by 4*s*. a week. Such is the statement. I do not give the astonishing total per cow for the year, because it is not to be taken for granted that the saving on winter food would be effected all the year round.

Mr. Lloyd states "that feeding experiments have

been conducted, those in Germany with greater care than anywhere else, and a brief sketch of the results is given" in the following Table.

Animal.	Live Weight	Food required per Day.				
		Dry Matter.	Digestible			Nutritive Ratio.
			Albuminoids.	Carbo-Hydrates.	Fat.	
Oxen, Growing—	Lbs.					
Age, 6–12 months ..	500	12·0	1·3	6·8	0·30	1–6·0
„ 12–18 „ ..	700	16·8	1·4	9·1	0·28	1–7·0
„ 18–24 „ ..	850	20·4	1·4	10·3	0·26	1–8·0
Oxen, Fattening .. per	1000					
1st period	..	27·0	2·5	15·0	0·50	1–6·5
2nd period	..	26·0	3·0	14·8	0·70	1–5·5
3rd period	..	25·0	2·7	14·8	0·60	1–6·0
Cow in Milk .. .. per	1000	24·0	2·5	12·5	0·40	1–5·4
Sheep, Growing—						
Age, 5–8 months ..	61	1·7	0·17	0·86	0·04	1–5·5
„ 8–11 „ ..	75	1·7	0·16	0·85	0·04	1–6·0
„ 11–15 „ ..	82	1·8	0·14	0·89	0·03	1–7·0
Sheep, Fattening .. per	1000					
1st period	..	26·0	3·0	15·2	0·5	1–5·5
2nd period	..	25·0	3·5	14·4	0·6	1–4·5
Horses at Work .. .. per	1000	22·5	1·8	1·12	0·60	1–7·0
Pigs, Growing—						
Age, 3–5 months	100	3·4	0·50	2·50		1–5·0
„ 5–8 „	170	4·6	0·58	3·47		1–6·1
„ 8–12 „	250	5·2	0·62	4·05		1–6·5
Pigs, Fattening .. .. per	1000					
1st period	..	36·0	5·0	27·5		1–5·5
2nd period	..	31·0	4·0	24·0		1–6·0
3rd period	..	23·5	2·7	17·5		1–6·5

Food for Dairy Cows.

In a lecture delivered by Mr. Lloyd,* as Chemist of the Dairy Association, on the value of fat as a constituent of the food of animals, he states:—

"Physiologists have been driven to the conclusion that the fat present in the food does not go direct to form fat in the animal body, but is broken up, and the fat of the animal formed anew." Into the scientific considerations on which this conclusion rests we need not enter here.

But the practical importance of the question, both to the dairy farmer and to the fattener of live-stock, is immense.

Does ready-made oil directly increase the butter or the fat of the animal? Or is it the most economical form of food for either of those purposes?

It is a well-known property of bean-meal, pea-meal, and decorticated cake (and I believe I may add of bran) to increase the flow of milk and the richness of milk in butter.

Here, then, we probably have another proof that Science is helping us to interpret practice, and in consequence to make practice more economical, more profitable, and more truly practical.

In a lecture delivered by Mr. Lloyd at Exeter

* 'Journal of British Farmers' Dairy Association,' vol. iv. part 1, 1888.

during one of the Itinerant Dairy Schools of the Bath and the West of England Society, he called special attention to the conditions requisite for increasing the production of butter. It is not, as might be supposed, to be obtained merely by increasing the fatty matter in the food; we cannot get the cream till we have got the milk.

The animal has four functions to perform; 1, to produce heat (to keep itself and its milk warm); 2, to produce flesh and bone (growth); 3, to put on fat; 4, to produce milk.

Referring to the third and fourth functions, Mr. Lloyd says:—

"Some people consider the production of fat is exactly similar to the production of milk, because milk contains so much fat; this, however, is an erroneous notion. The production of fat inside the animal is the production of fat only; the production of butter-fat in the milk is accompanied with the production and formation of other compounds which exceed in quantity the actual fat in the milk. There is as much casein, of which cheese is made, in ordinary milk as there is butter-fat. Therefore, unless the cow be fed so that she can form casein as well as butter-fat, she will not produce milk. In the formation of fat in a fattening animal there is no formation of casein; the two things, fat production and milk production, are, therefore, distinctly different."

Towards the end of the lecture he adds :—

"Lastly, I want to say a few words with regard to food in connection with the Dairy. It has been found that the Dairy cow, owing to the casein that it produces in the milk, requires in its food nitrogenous substances to a far greater extent that one would imagine, and, so far as can be ascertained, milk is produced by the same substances as those which produce flesh.

"The standard for the milking cow is that it should have 24 lbs. of dry matter in its food per day, which dry matter should contain 2½ lbs. of albuminoids, about ½ lb. of fat, and 12½ lbs. of carbo-hydrates (starch and sugar). In 100 lbs. of milk there are 87 lbs. of water. Water has to be raised to the temperature of the cow, and in order to do that the cow must, like the steam-engine, burn a certain amount of fuel, or food, to produce that heat. I therefore advise you to warm your water, because if you do so you will see the benefit in the milk-pail, and much less food will subsequently be required to warm that water inside the animal. That is why it is generally found best to prepare, steam, or cook food for dairy cows. One advantage in this is that the cooking gets rid of detrimental substances which are in some foods, and are troublesome in the production of milk. Silage, whether sweet or sour, of course within certain limits, produces good

milk. You not only want warm food and water, but you must not give cows indigestible food, which will cause them to labour in its digestion."

In another paper written for the British Dairy Association, Mr. Lloyd says, "The dairy farmer is well aware that cows vary according to their breed, that, feed how one may, a Jersey or Guernsey cow cannot be made to yield the quantity of milk given by an Ayrshire or Shorthorn, nor an Ayrshire or Shorthorn yield milk of the same quality as that given by the Jersey or Guernsey. . . . It follows that different breeds require different feeds." There will also be individual peculiarities in the same breed. He refers to important experiments by Mr. Tisdall of Kensington, and to the need for weighing the animals, and keeping a record of their produce. Only by such means can the maximum yield of milk, butter and cheese be obtained at the minimum expenditure. The chief points noted, are, where butter is the main consideration, increase the albuminoids—for the production of milk in quantity give succulent food, and feed frequently. For cheese, increase the flow, and keep down the fat. For rich cheese, giving albuminoids will increase the fat, but the manufacture of cheese from rich milk requires special care.

PART IV.

PRACTICE WITH SCIENCE.

CHAPTER XII.

THE purpose of the pages which follow is to promote the co-operation of the practical farmer with the agricultural chemist, in the explanation of farm practice, and the application of scientific truths to the improvement of practice. It may be excusable, therefore, if a few words are offered on the present relation between "Practice and Science," or "Working and Learning."

A very distinguished chemist, the second Sir Benjamin Brodie, said to me many years ago, "The farming of England is a long way ahead of the science of Agricultural Chemistry. It will take half a century for the science to catch the practice." More than a quarter of a century has passed, and though science is gaining on its forerunner, I am not sure that it will win the race before the half century is over.

The practical man and the man of science both

desire to *get at the truth*, but for different ends and by different roads. The practical man is he whose business it is to make, or do something; he is always acting, dealing with a number of details, many of which are not under his control. On most points he has made up his mind, or inherited the opinions of others; he has to come to a decision quickly, act on it at once, and await the result perhaps for a year.

The man of science, on the other hand, aims at knowing rather than doing; he tries not so much to deal with results as to account for them by finding out their causes. His first step is to accumulate and arrange in his head, with minute accuracy, the knowledge of other men of various ages and lands. His next is to isolate some one point on which little is known and to work it out —he can bide his time, and be slow in drawing conclusions. If he is wise, he will be cautious in applying them to practice. It follows that, owing to the fact that the farmer and the philosopher travel by different roads, they do not always give the same account of the country they travel through.

But though there be much difference in their way of dealing with facts, they can do much to help each other. And at the present time the leading men in each department have learned to respect the judgment of those in the other.

I think I may without offence say now, as I have

said, on many important occasions before, on the highest authority, the great thing to be desired for the rising generation of farmers is a *good, sound, general education*, one which will teach them the intelligent and accurate *use of language*, the sound principles of *calculation*, and will sharpen their *powers of observation*, opening their minds to the reception of something more than the local traditions of their neighbours. By this I mean mental training, not an acquaintance with a number of sciences. So far as science helps the young farmer to observe and to reason, well and good. As mere information, an acquaintance with scientific facts or theories, derived from books only, is very likely to lead him to make serious blunders.

I may perhaps be allowed to point out that while the branches of science which bear on Agriculture are more numerous than those which bear almost on any other subject, there are three departments of enquiry which lie at the root of Agriculture, as of Natural Science generally :—

1. What are the properties of matter (so to speak) in the mass (whether solid, liquid, or even gaseous)? this used to be called Natural Philosophy, it is now called Physics.

2. What are the elements composing matter, and the laws of their composition and decomposition? this is Chemistry.

3. What are the laws by which the various

organs act in living bodies? this used to be called Physiology, it is now called Biology, or the science of life.

The late Dr. Voelcker told me that, after long experience on the Continent and in Scotland and England, he did not consider Chemistry a good subject for education in school. Mechanical laws are more adapted to school discipline, and within certain limits the Physiology of plants and animals may be made to awaken healthy interest in the young.

But as regards the adult farmer, the best course for him is to consult the chemist as he would consult the family doctor. Only he should try to learn enough of the meaning of chemical terms and the laws of nature to put his questions intelligently.

I hope the general reader will excuse this rather academical lecture, delivered not for the first time, but still much needed in high places.

The following slight sketch of facts and principles was hastily prepared three years ago with immediate reference to the proposed action of Local Societies in conjunction with the Royal Agricultural Society.

I am aware that there is some repetition of what has been dealt with in the first chapter of this volume. But I have been advised to insert this reprint as presenting the subject from a different point of view, more practical and less technical.

I was a little fearful lest we should be drawn

into speculative questions without the requisite means for accurate scientific investigation and experiment under competent guidance. I feared also that we might miss the opportunity of enlisting practical farmers in such work as they are especially able to promote. I hope we are now moving in the right direction. Several important Local Societies have determined to apply some of their funds, and, what is more important, their practical skill and intelligence in most useful local enquiries.

I thought I might render some little service by pointing out to my brother farmers the practical benefit which may now be derived from a closer connection between Practice and Science; between common facts of experience, and careful and accurate examination of the causes of those facts.

With this object in view, I endeavoured in the most homely manner to suggest some of the questions on which we require more light, and to indicate some of the sources of information which appear to me at once thoroughly sound and trustworthy, and also easily accessible.

I need hardly say that I lay no claim to be an authority either on practical farming or on scientific investigation. I have long been a learner, and only desire to pass on in the simplest language what it has taken me long to learn. Above all, we need to learn how much there is which we do not know yet.

It may, I think, be taken for granted—

1. That the object now in view is not so much to discover *unknown scientific principles* as to spread the knowledge of *established principles* among practical farmers, and at the same time to bring them to the test of practice, of profit or loss.

2. That there are matters of *recognized practice* in Agriculture, the *explanation* of which is possibly not clearly settled, or, at any rate, is not generally understood or accepted.

3. That there are *facts and principles,* clearly established by science at Rothamsted, Woburn, and elsewhere, which need to be *verified* in other places, on different soils, and under various climates.

I propose to deal with the second and third points, the explanation of practice, and the illustration of ascertained truths supposed to be established by science.

PRACTICE

Needs Interpretation by Science.

Traditions of Practice.—To begin with practice. Every district has its own traditions. These traditions have generally a substratum of fact. But the facts are often overlaid by a confused medley of obsolete theory. Sometimes, on the other hand, new theories, half truths, are taken up hastily, in

disregard of qualifying circumstances overlooked. For instance, it might be supposed that we all know what is the meaning of "fertility," what is meant by a "rich or poor soil;" what is meant by "good heart and condition;" what is meant by "exhaustion of soil." But do we really know the facts or the causes? I am sure the most highly educated surveyors would confess that their knowledge is empirical and imperfect. In other words, that it is practical judgment and insight based on experience rather than on clear knowledge of causes.

We are all familiar with the paramount importance attached to farmyard manure, and the assumption of infallibility which attaches to the traditional dogmas on the subject of muck and lime, to call which in question is deemed rank heresy.

I asked a neighbour of mine, a worthy specimen of the small holdings tenant who is the coming man of land reformers, what manure he used. His reply was—"I don't like that bag stuff. I say stick to the black and the white," i.e., *rotten dung* and lime.

There is also an opinion widely prevalent that artificial manures stimulate plant growth and exhaust the soil—and another opinion is that land requires rest.

It may be worth while to try to elucidate the meaning of these venerable traditions, with a view to the more profitable application of any truth which they may possibly imply.

There are two opposite tendencies of opinion; some old-fashioned farmers are ever desirous for a manure which will be lasting. But these old-fashioned farmers are decreasing in number. Clear-headed practical men now look for quick returns, and need information on which they can rely.

Some farmers, especially amateurs, of a younger, and perhaps not a wiser school, seem to think that by analysing the soil and analysing the crops we desire to grow, we can at once find out what food the plants want.

Statements by writers of high scientific repute and authority, without practical knowledge, sometimes support this opinion, and are misleading.*

* I find the following statement in the English edition of M. Paul Bert's famous book, of which in three years 500,000 copies have been sold in France. There is scarcely a school, even in the smallest village, which does not use it.

"It is necessary to give back to the soil precisely the substance the plant has consumed in it."...Wheat contains phosphorus: hence phosphates, crushed bones, will greatly facilitate its vegetation."..."All this is plain enough, and easy to understand as a principle." Not to mention that every plant, especially every seed, contains phosphorus, this statement omits the most important outcome of Rothamsted work, as to the connection between wheat and nitrogen.

M. Paul Bert's book, 'First Year of Scientific Knowledge,' translated by his wife (a Scotch lady) and modified to suit English schools, is a marvel of teaching skill, and cheapness. It deals with animals, plants, and soils; it gives the elements of Physics, Chemistry, and Physiology. It contains 549 woodcut-illustrations, and costs only 2*s.* 6*d.* Publishers: Relfe Brothers, Charterhouse.

Interpretation of Practice.

It appears to me that experiments on practical farms in different districts may do much to make known probable answers to the questions which I have indicated above, and to spread the knowledge of the principles which underlie the practice. It would be premature to offer any solutions at present, but one or two suggestions may be hazarded as to the line of enquiry.

To take the soil first, and its inherent capabilities; supposing that in any instance it contains all the elements of plant life, it may not be in suitable mechanical condition, such that the roots can penetrate it; or the constituents may not be in such a combination chemically that the roots can feed on them.

Therefore fertility, natural richness, or high condition, may involve properties either mechanical or chemical, or both. As regards mechanical action, the practice of good tillage farmers of the old school in favour of working the land well is confirmed by scientific enquiries as to the action of roots; and certainly the practice of the gardener with his repeated double trenching is not favourable to the theory of rest.

On the chemical constituents of the soil regarded as essentials of plant growth much has been recently written (especially by Mr. Jamieson in connection

with the Sussex Association). The truth, however, has long been known that there are a certain number of elements *essential* to plant life which are to be found in most soils in sufficient quantities, and that only a few elements have to be supplied in manure because they are not in the soil either in sufficient abundance or in an available form for immediate use.* (See Appendix, p. 201.)

If we turn from the state of the soil to the question of manure; as milk is the type of a complete human food, so rich farmyard dung may be regarded as a complete plant food. But the action of dung is perhaps imperfectly understood. There is a common impression that dung contains ready-made vegetable food for plants; this opinion is almost certainly erroneous. But the effect of the vegetable matter of dung in retaining valuable food for future crops is a truth to be acted upon with discretion according to local circumstances.

* Any one who wishes to learn what is really known about the soil and the essentials of Plant life should study carefully the second chapter of Mr. Warington's 'Chemistry,' pp. 14–22. See also Chapter I. pp. 2, 3.

He will then see that sulphur (which has been spoken of in Sussex as poison to plants) is an essential element of plant life, and of the flesh of animals. The other mineral essentials are phosphorus, potash, lime, magnesia, iron. See also Masters' 'Plant Life,' pp. 12–14.

It must not be overlooked that the question of what is *essential in plant life* is not the same question as what is *essential as an element of manure.*

I once asked a skilful and experienced gardener for his opinion on the value of dung. He named the following points. It acts as a sponge for liquid manure;—it opens the soil to the action of the air, —to the movement of worms,—to the penetration of roots;—it raises the temperature of the soil;—it retains moisture.*

Lime, again, has a great reputation, especially in the West of England; its action as a corrective of sourness, and its influence on artificial manures, require illustration.† Again, the supposition that certain artificial manures have a stimulating and consequently exhausting effect needs to be tested and illustrated by well-devised experiments.

It is not an uncommon idea that the stiffening of wheat-straw depends on silica. I remember a manure agent taking advantage of this idea by advertising wheat manure with a large percentage of silicious constituents, derived probably from a neighbouring sand-pit. The more probable action of lime and salt may be one deserving to be tested by experiment, and explained by science.

Before I attempt to state more precisely a few of

* Another important function of dung is its effect in converting inert matter into useful food. Mr. Warington has pointed out how little living things called Bacteria act in fermenting material such as dung. Ammonia-salts applied to some soils do no good, unless ferment bodies are present.—Masters, 'Plant Life,' p. 12. See also Warington, p. 17.

† As to the action of lime, see Warington, 'Chemistry of the Farm,' pp. 15–32.

the problems for local experiments which appear to be suggested by the principles established at Rothamsted and Woburn, I hope I may, without offence, suggest that there are certain facts of nature which are not recognized by all practical men—such, for instance, as the great proportion of water contained in some crops, or the fact that the greater part of the solid matter of all plants is derived directly from the atmosphere. I will set out a few facts, the knowledge of which is of primary importance for the conduct of experiments, and not less needful for the intelligent observation of them.

Plain Truths.

Facts of Nature.

Plants require three kinds of food—*water*, *mineral matter*, and *gaseous matter*—and to use these foods they require *warmth.*

Here we have the old-fashioned four elements—*water*, *earth*, *air*, and *fire* or heat.*

* I derived this illustration of the four elements from a lecture delivered in 1848, at the Royal Institution, by Professor Sir Benjamin Brodie, which it is a pleasure to remember.

The Primer of Sir H. Roscoe opens thus: "There are four things we all know well. Let us try to learn what Science teaches us about them.....It is either by observation or experiment we learn all we know about what goes on around us. To find out and explain what goes on when *Fire* burns—how the *Air* makes the fire burn or *helps the plant to grow*—to find out what *Water* is made of, and to learn the

How much of each do the plants require?

From what sources do they derive each food?

Many practical men are surprised when they are told that 100 lbs. of turnips contain 90 per cent. of water, or 9 gallons; and that of the remaining 10 lbs., 9 lbs. are derived from the air, leaving only 1 lb. to be derived from the soil. I give the proportions roughly—the particulars are in a note at the foot of the page.*

The facts just stated cannot be called theory; they can be tested by any one who has an oven, a fire, and a pair of scales.

There are many other facts, such as the composition of various parts of animals—viz., fat, flesh, bone—the constituents of their food, and the

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many different substances which can be dug out of the *Earth*, all this belongs to the Science of Chemistry."

* The following figures are taken substantially from Dr. John Voelcker's Lecture at the Kingscote Agricultural Association—but they are given in round numbers, avoiding decimals. See also table in Warington's 'Chemistry of the Farm,' p. 38.

The average composition of turnips, swedes, mangolds and potatoes, percentage in 100 lbs.:—

	Turnips.	Swedes.	Mangolds.	Potatoes.
Water	91½	89½	88½	75
Flesh-forming matter	1	1½	1½	2
Fat, Sugar, Starch and fibre	6¾	8¼	9	22
Minerals	0¾	0¾	1	1
	100	100	100	100

constituents of their excrements, which can equally be ascertained by weight and measure, but which may require a little more skill to test by what we call analysis. These facts also are not theory, and their bearing on profit and loss is most practical.

The practical questions arise—what can man do to assist the growth of plants by cultivation or manure, or the production of animal food by judicious breeding and feeding?

Established Truths of Science.

I now pass on to *scientific truths* fully established, as to the means by which plants live and grow, and die.

I must beg the indulgence of my scientific friends and teachers if I speak in a language "understanded of the people" rather than with scientific precision.

Speaking then generally, plants obtain their *water* through their roots—by roots we mean only the little fibres. The varying form and direction of these roots has much to do with the proper use of manures.* It also deserves especial attention in the selection of grass seeds and in the management of pasture.

* See Mr. Maskelyne's paper, quoted p. 93.

Plants obtain *mineral matter* also through their roots, but only in a thoroughly soluble state. They must receive this mineral matter in a wholesome form, not highly acid, generally in the form of what is called a neutral salt, before it can be taken up by the plant as a wholesome food. But whatever the chemical property, the mineral matter must be absolutely soluble.*

The *gaseous matters* referred to above are chiefly carbon in the form of carbonic acid, and nitrogen in the form of ammonia.†

Carbon is the chief part of the solid matter of all plants left after the water has been evaporated, and appearing as a black, charred mass of coal or charcoal. This black mass, however, contains some nitrogen and some mineral matter. All this carbon is imbibed, or rather, I should say, inhaled by the leaves from the atmosphere. The leaves are at once the lungs and the digestive organs of the

* Maxwell Masters, 'Plant Life,' p. 20.

† As to carbonic acid, see Roscoe, article 2, page 10; article 33, page 58; also article 48, page 82. As to nitrogen and its connection with the elements of water, hydrogen and oxygen, forming ammonia and nitric acid, see article 47, page 79. On the action of animals and plants on the air, see article 13, page 29.

"We have learnt that **Animals** inhale (breathe in) oxygen and exhale (breathe out) carbonic acid—give off heat—are constantly burning. **Plants** inhale carbonic-acid gas and exhale oxygen, take up the sun's light and heat, without which they cannot grow, are constantly forming material that will burn."

plant, and their healthy condition is literally vital.* (See Appendix, p. 206.)

Nitrogen is essential to the life of a plant. It is abundant in the atmosphere, but the plants cannot feed on it directly as a simple gas. It is one of the elements of ammonia, and one of the elements of nitric acid. Nitric acid, when combined with lime, or potash, or soda, is called a nitrate. Nitrates are of the utmost importance in the soil and in manure, also in water used for irrigation. They are very soluble, and liable to be washed out in wet seasons.†

It was not long ago believed that nitrogen could be absorbed as well as carbon by leaves, especially in the case of beans and clover. This is now, if not disproved, at least very doubtful. So far as those crops prepare for wheat, they do so by sending down long roots and bringing up nitrogen near the surface from a considerable depth.

It used to be supposed that the food of plants was to be found ready-made in the earth, and that it was drawn up through the roots. It was called humus. It is all but certain now that this is not so, and that vegetable matter in the earth must be decomposed before farm crops can benefit by it.

* See 'Feeding by Leaves,' 'Plant Life,' pp. 24–26.

† As to the importance of nitrates, and the conversion of ammonia into nitric acid, see Warington's 'Chemistry of the Farm,' p. 8.

There was once an idea that plants excreted certain matters into the soil. The need for rotations of crops was supposed to rest on this principle. It is now known that "root excretions have no existence." *

When a plant has come to maturity, and is available for the food of animals, it contains two distinct classes of compounds. One of these will not make flesh or bone, but only fat; the type of this food is starch. The other class will supply nourishment both to the flesh and to the bones. The type of this food is the gluten or sticky part of wheat flour left after the starch has been washed out.

Under the first or fat-making class are included sugar and oils. Under the second are included various substances akin to white of egg or albumen, called albuminoids. The first class contains, besides the elements of water, only carbon. The second class contains also nitrogen and some mineral matters—especially phosphorus and sulphur.†

* For "Root action—what roots do," see 'Plant Life,' p. 20.

† The essential basis of life in all plants is a viscous or gummy substance called *protoplasm*, without it the plant dies. This contains, besides carbon and the elements of water, nitrogen, sulphur and phosphorus. Phosphorus seems specially needful for the formation of all grain or seeds without exception. See Masters, 'Plant Life,' pp. 12, 13.

The proportions in which starch, oil, or sugar foods, on the one hand, and albuminoids on the other, are to enter into the feeding of animals, so as to avoid waste, are of the utmost importance to the farmer. See Chapter viii.

It must be obvious that these elementary truths of science have a practical bearing both on the growth of crops and on the feeding of animals. To give only one illustration. If it be true (as it certainly is) that butter and fat contain only carbon (not reckoning water), and that all this carbon is obtained from the atmosphere, it is obvious that the land is not impoverished by the sending of butter to market (the skim-milk being consumed on the farm), as it is by the sale of cheese or raw milk. Nor does the sale of fat animals, bought as stores, send off the materials required to build up the bone and flesh of animals bred on the farm. It is obvious also that this consideration has a bearing both on the manures to be purchased and on the unexhausted manurial value of different kinds of food consumed on the land.

Science

Needs verification by practical application.

I now pass on to one main purpose of this part—to indicate by way of illustration a few of the truths, both scientific and practical, which we owe to the lifelong work of Sir J. B. Lawes and Dr. Gilbert, and of the late Dr. Voelcker. These truths, worked out at Rothamsted and Woburn regardless of expense, it is now desirable to verify

on practical farms, and to endeavour to turn them to account in the spirit of the most severe economy imposed upon us by necessity. I will first refer to the capabilities of the soil, and go on to the effect of manures and cultivation. I will do so in the fewest and simplest words.

Rothamsted and Woburn, Facts and Principles.—On an average clay soil (*kept strictly free from weeds*) wheat has been grown, *without any manure*, year after year for forty years. The average produce at first was about 16 bushels per acre; it is now rather less, about 14 bushels. We have here the starting-point, or what engineers call the datum-line, from which to measure all subsequent experiments *on that particular soil.* We want similar data for other soils, but that will be the work of some years.

In order to test the effect of *bare fallow*, wheat has been grown on two contiguous half-acres in alternate years, each plot being a bare fallow in alternate years. For the first few years the wheat after fallow exceeded the produce of wheat grown after wheat by about 20 bushels.

At the present time the land on which crop and fallow have been carried on alternately for thirty years yields little more per acre in any one year than land continuously cropped for forty years. Taking the total produce for ten years, the land under continuous wheat-crops has produced per

acre 150 bushels; the alternate crops have only produced per acre 90 bushels, or at the rate of 6 bushels per acre less for each year.

We must not jump to the conclusion that occasional fallows are never desirable, but the facts stated suggest further experiment in different districts.*

These facts relating to the soil at Rothamsted, suggest the importance of testing the inherent capability of such soils as the poor clays in North Devon and West Cornwall, the thin soils on the Chalk Hills, the heavy clays of Essex and the Midlands, the peculiar soils on the oolite series, and the barren soils on moorlands and gravels.

I gathered from the late Dr. Voelcker, that on some of the more barren soils deficient in available constituents of plant food, the possibility of applying artificial manure with the prospect of profitable cultivation could not be entertained. In certain cases he thought a heavy dose of lime might produce better herbage. I understood him to mean that no amount of minerals which could be afforded would be sufficient to enrich a poor soil: the effect of artificial manure being chiefly to promote the early growth of a plant so as to enable it to forage for itself, if the desired mineral or nitrogenous food was to be found for seeking.

* The results of a bare fallow are clearly explained in Warington's 'Chemistry of the Farm,' page 50.

He did not deny that good cultivation and cropping would gradually improve soil. But he often told me that the unexhausted value of artificial manure was much exaggerated, and therefore we should only apply enough for each crop in turn.

So much may suffice as to the capabilities of the soil, remembering always that at Rothamsted no weeds have been allowed.

Now as to the effects of manures.

The present generation can hardly realize the intense interest of the controversy between Baron Liebig and Sir John Lawes as to the mineral theory.* Suffice it to say that the farmers of the present day owe to Rothamsted the establishment of the great principle that a special supply of nitrogen is indispensable for the full wheat crop, and of phosphates for the turnip crop; and further, as regards both crops, that the two elements of manures in due proportions, and at proper times, whether as dung, artificial manure, or animal excrement, are essential to profitable cultivation.

A short statement of facts may give a tangible illustration of the principle:

	Bushels.
Soil unmanured, as stated above, has given	16

* On this subject, reference may be made to the Historic Sketch, p. 89.

During 32 years, 1852-1883—

	Bushels.
The average produce of dung has been about	$33\frac{1}{2}$
The average produce of minerals* and nitrate of soda	36
The average produce of minerals* and salts of ammonia	33

The nitrogenous manures applied were—dung, 14 loads per acre, containing 200 lbs. of nitrogen applied every year; 350 lbs. of nitrate of soda, containing 86 lbs. of nitrogen; 550 lbs. of salts of ammonia, containing 86 lbs. of nitrogen, each per acre every year.

There must have been a great waste or accumulation of nitrogen due to dung which has not been available.

Much of the nitrogen in the artificial manures, especially the nitrate of soda, was probably washed out in wet seasons. It must be remembered that there was no addition of vegetable matter like straw to store up the nitrogen.

The experiments carried on at Woburn confirm these facts and point to similar principles.

* The minerals used at Rothamsted, and afterwards, for the sake of uniformity, at Woburn, contained potash, soda and magnesia, in addition to about 3 cwt. of phosphates. I gather from such enquiries as I have been able to make that soda and magnesia are not required in manure for ordinary soils, potash only in special cases.

It will be obvious to the practical farmer that the cost of the manures applied at Rothamsted has been very heavy, 86 lbs. of nitrogen, whether in the form of nitrate of soda or of sulphate of ammonia, together with 3 cwt. of phosphates, cannot be estimated at less than 3*l.* 200 lbs. of nitrogen, in the form of 14 loads of dung, would probably cost rather more.

One point is clearly shown by the Rothamsted and Woburn experiments, viz., that an addition to the above-named amount of nitrogen produced no corresponding effect; in Dr. Voelcker's words, "excessive doses of nitrate of soda or salts of ammonia cannot be applied to corn crops without incurring great loss." The experiments also show that a small amount of nitrate of soda or of salts of ammonia has a more powerful immediate effect than a larger amount of nitrogen in the form of dung, *provided there is an adequate supply of minerals in the soil or in the manure.*

We now know for certain that the important elements of manure are very few—nitrogen and phosphorus on almost every soil—potash only on certain soils. Lime, as above remarked, is rather a means of improving the capability of the soil than an actual manure, or plant food.*

It would seem, therefore, that one of the most important points to be tested on farms is the

* *See* Warington, 'Chemistry of the Farm,' pages 15, 32.

amount of nitrogen which can be most profitably supplied to each crop in a form immediately available.

Another very important point shown by the Rothamsted experiments will come home to every farmer, namely, the effect of different seasons. It may be illustrated by the following table, which gives the produce of wheat with mineral manure and nitrate of soda.

Seasons.	Wheat.	Straw.
Produce in the best season, 1863 ..	55 bushels ..	6312 lbs.
" " worst season, 1879 ..	22 " ..	4347 "
Average of 32 years, 1852–1883 ..	36 " ..	4688 "

I have heard it suggested that experiments in the open field on ordinary farms will prove nothing about the effect of manures, unless the soil be first exhausted and analysed. I take the liberty to express a directly contrary opinion. I think what the farmer wants to know is the effect of artificial manures on his farm in the state in which it now is, be that state one of poverty or of fairly good condition.

What we all want is to get that information as to comparative results with careful accuracy, and exclusion of disturbing causes affecting the result.

It will, of course, be desirable to have a correct record of the previous history of each field on which experiments are tried. More will probably

be gained by the comparison of a large number of results under varying conditions than from any one case, however carefully prepared for scientific enquiry.

The practical results obtained by Mr. Prout at Sawbridgeworth with continuous corn growing an a large scale are very instructive.* It appears that he applied in various forms about 38 lbs. of nitrogen, less than half the amount used in the Rothamsted and Woburn experiments; he used also an amount of bone manure, which Dr. Voelcker thought needlessly liberal.

Root-crops.—I do not enter in any detail on the subject of experiments on the growth of root-crops. It is well understood that they must have the help of artificial manure, especially phosphates in their early state. It may be well to set on foot some experiments, with a view to decide the question how far the large supply of dung usually given to roots is needful; † and whether if the dung is put into the ground with a view to future corn-crops, it might not be more economically and profitably applied on grass in preparation for corn.

We are now in possession of accurate information on the amount of each kind of matter removed from the soil by different crops of roots. Dr.

* 'Profitable Clay Farming.' Stanford, London, 1881.

† See the Report of Experiments on Mangold in 1890, page 192.

Voelcker's table, given in the footnote,* gives the facts in a concise form. But further information is needed as to the feeding quality of roots grown on different soils, and with different manures. This is a subject on which some practical farmers are very desirous for accurate knowledge. They are rather disposed to think that turnips grown with artificial manure cannot be so nourishing as those

* An admirable summary of Science and Practice will be found in a Lecture on Root Crops, delivered to the Kingscote Agricultural Association by Dr. John A. Voelcker, in Feb. 1886. Published by Harmer, Cirencester, price 6*d.*

The following table is taken from his Lecture, and from Warington's 'Chemistry of the Farm.'

The principal constituents of manure removed in ordinary crops of turnips, swedes, mangold and potatoes given in lbs. per acre :—

	Phosphoric Acid.	Potash.	Nitrogen.
Turnips, 17 tons ..	33	148	120
Swedes, 14 „ ..	21	79	102
Mangold, 22 „ ..	49	262	147
Potatoes, 6 „ ..	26	76	67

It is useful to compare these constituents removed by roots with those removed by corn-crops :—

	Phosphoric Acid.	Potash.	Nitrogen.
Wheat, 30 bushels, and straw ..	22	27	45
Barley, 40 „ „ ..	20	31	47
Oats, 45 „ „ ..	19	38	52
Beans, 30 „ „ ..	31	81	99

It may surprise some practical men to observe how much more is taken out of the land by root-crops, if removed, than by corn-crops. Especially it may be noticed that the amount of nitrogen, the most expensive item in manure, is three times as great in a crop of mangold as it is in a crop of wheat.

to which dung has been applied. The experiments on Mangold, recorded further on (page 192), throw light on this question.

Grasses.—Experiments on grasses are going on, and more are proposed. I confess that I entertain considerable scepticism as to the value of experiments on the effect of manures on individual species of grass.

It would, however, be very useful to young farmers if their fathers would get an ounce or two of all the best grasses and sow them on plots in a garden separately, and also a few in mixtures, with a view to study their times of flowering and seeding and other habits, such as the forms of their roots.

The experiments of Sir J. Lawes on the permanent pastures of his grass parks are well known. The result is admirably summarized in Dr. Maxwell Masters' 'Plant-life on the Farm,' chapter vii., "The Battle of Life in the Meadow." The tendency of nitrogenous manures to develop the coarse grasses, of mineral manures to favour the leguminous plants, is now an accepted principle.

The Rothamsted grass parks have been annually mown, not pastured. The relative value of manure on feeding pastures cannot be satisfactorily tested by weighing hay (see page 190). But I understand Sir John Lawes (speaking in his capacity as a practical farmer, not as a scientific enquirer) to counsel that we should not rely much on the

selection of special seeds, but rather manure the natural grasses well; leave the rest to the taste of the cattle, and to the effect of oilcake both on them and the grasses.

It must be borne in mind that grasses grow in company. Much depends on the time at which each species forms its seeds, and consequently on the time of mowing meadows for hay, and the time of stocking and unstocking pasture. If due attention is not given to these points, some of the coarser grasses will stifle those which are most important. This consideration throws light on the common idea that the grasses natural to the soil are sure to prevail. This prevalence is in many cases simply due to bad management.

Experiments on Food for Animals.—There is one other subject on which we need experiments under the ordinary conditions of farming, that is the effect of particular foods on the produce of meat and milk. If I remember right, Sir J. Lawes showed that about 150 lbs. of average roots were required to produce 1 lb. of meat.* We certainly need to

* Since I wrote the words in the text from memory, with reference to important experiments carried on twenty years ago, I have been able to refer to the article on the "Valuation of Unexhausted Manures," by Sir John Lawes and Dr. Gilbert, in which there is a Table II., page 15, showing the fattening increase in live-weight (of oxen and sheep). It is there stated that 150 lbs. of white turnips will produce 1 lb. increase; or, in other words, 1 ton will produce 14½ lbs. The statement in the text must be qualified, by observing

bring the question of food to the test of weight and measure, but I fear this is too large and complicated a subject for any local Society to enter upon.* Important experiments on the feeding qualities of ensilage in comparison with hay and roots have been conducted at Rothamsted and Woburn.

I have not touched on the subject of the Dairy, because it seems to me that what we need is not so much experiments as industry, method and skill in acting on what is already known and generally applicable. But on this branch of farming accurate records of produce on different systems are much to be desired. The beneficial effect on the practice of butter-making and cheese-making of the Dairy Schools of the Bath and West of England Society, organized by Mr. George Gibbons, is now well known.

The Milking Trials of 1890, conducted by the

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that the increase is increase of live-weight, not saleable meat. It is also to be noticed that the figures are given on the assumption that the food is not given alone, but in judicious amount and admixtures with other foods, each of which would give its proper amount of increase also.

* I may, however, refer to recent numbers of the Bath and West of England 'Journal,' as containing some careful records of the feeding of animals, periodically tested on the weighbridge on my farm by my estate steward, Mr. W. Stevens. On the whole question of food, see Warington, chapter v., "On Animal Nutrition:" "On the Organs of Digestion," Brown, 'Animal Life,' chapter ii.

British Dairy Farmers' Association, as described by Mr. Lloyd, the Consulting Chemist of the Association, will, if continued, have a great educational value. It is becoming more evident every year that we have much to hope from the explanation by Science of the experience of the Dairy farmer. To take only one point, the ripening of cream for butter, the importance of this process is admitted; but how little we understand about its causes, or the means of regulating it?

CHAPTER XIII.

NOTES ON PRACTICAL FIELD EXPERIMENTS.

There can be little doubt that a combined effort to bring the scientific investigations of the last quarter of a century to the test of practice on ordinary farms is a step in the right direction.

It is, as I have stated already, p. 133, not the main point now to establish new experimental stations with a view to scientific discoveries, but to invite the aid of intelligent landowners, land agents, and occupying farmers, in different districts, for the purpose of simultaneous experiments of a simple kind, under conditions strictly practical.

At the risk of laying myself open to the charge of being unpractical, I will venture to say what I think is not beyond the bounds of possibility.

1. Is it not possible, with our present knowledge of the constituents of manure, and of the requirements of plants, to apply *year by year* just that amount and kind of manure which each crop requires?

2. Is it not probable that, with an outlay for manure not much exceeding twenty shillings per

acre in each year, we may grow a succession of corn crops more cheaply than we have grown two crops in four years on the system of alternate rotation? May not straw be made more directly remunerative?

The suggestion of successive corn crops proceeds on the supposition that, in order to keep the land clean, the autumn and spring will be used effectually in preparation for spring corn, if the land is not clean enough for sowing a crop in the autumn.*

3. If, as many practical men think, land requires rest, may not this object be best attained by prolongation of grass crops, with careful choice of seeds, and judicious amelioration, either by means of artificial manure, or cattle food, or dung, and so prepare for another succession of grain crops?

I do not of course intend to overlook the necessity for roots, whether for winter food or for cleaning the land. In the West of England grass after turnips is considered the best farming. Nor must ensilage be lost sight of.

Conditions suggested for Local Experiments.

It appears to me that certain conditions may be laid down for practical experiments:—

* See the reference to Mr. Prout's Clay farming, p. 152.

1. They should not be on a very small scale.*
2. They should not be complicated.
3. The object of the experiments should be to put a few questions to the test of practice in a number of places during the same season.
4. The mode of sowing crops, applying manures, and gathering crops, should not be troublesome.
5. Some simple means of testing results with uniformity and sufficient accuracy should be adopted.
6. The manure should be supplied gratuitously, and provided on the responsibility of a competent chemical adviser.
7. There should be a careful registry of the following facts relating to each field in which experiments are made.
   (*a.*) The physical texture and condition of the soil, stiff or friable, heavy or light, wet or dry, close or porous.
   (*b.*) The chemical constitution of the soil, tested with special reference to lime, phosphoric acid, potash, nitrogen.
   (*c.*) The elevation and aspect of the field.
   (*d.*) The rainfall and temperature of the season.
   (*e.*) The previous cropping and treatment of the field.

8. A competent assistant to the directors of the

* The late Dr. Voelcker said that one-tenth of an acre should be the smallest size for a field experiment.

experiments will probably be needed, who should give proof of his familiarity with all operations of cultivation and harvesting, and also of his having had a good general education, which should have included especially a sound training in Elementary Mathematics, in order to secure sufficient accuracy in recording facts. It would also be desirable that he should have had some short training in what is called Practical Chemistry, as distinguished from attendances at lectures or reading text-books.

Plan for an Experimental Field.

I would suggest as a tentative scheme a plan which appears to me simple and easy to be carried out simultaneously by several practical farmers. (See diagram, page 162.)

The area of each experiment should not be less than five acres, ten acres would be better.

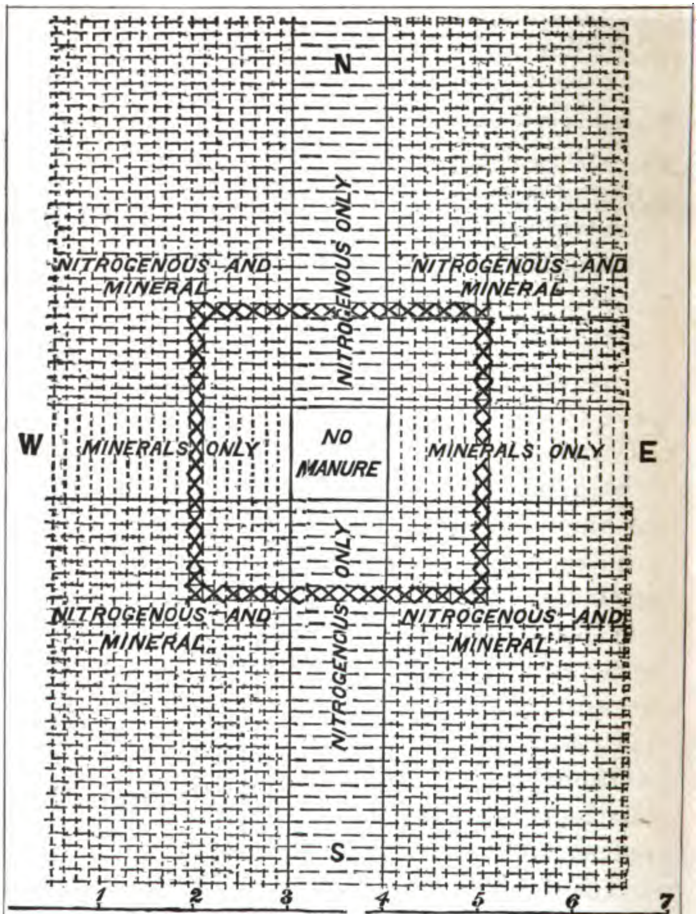
One or more plots in each field should be left unmanured.

Mineral manures should be distributed in one direction.*

Nitrogenous manures at right angles to the minerals. So that there may be clearly marked plots on each area.*

* **These suggestions were admirably adopted and improved upon by Mr. Lovelace of Winsford in some experiments on oats, described on page 180.**

DIAGRAM FOR EXPERIMENTAL FIELD.



SCALE HALF AN INCH TO A CHAIN.

EXPLANATION OF DIAGRAM FOR EXPERIMENTAL FIELD.

The points of compass are only put in for convenience of explanation.
The Central Plot has no manure.
Nitrogenous manures, indicated by horizontal lines ——— are to be distributed from W. to E. (above and below the strip with Minerals only).
Mineral manures, indicated by vertical lines ||||||||, are to be distributed from N. to S. (right and left of the strip with Nitrogen only).
The mark XXXXXX indicates a fence to keep off cattle and sheep (*in the case of grazing pasture only*).
There will be inside the fence nine plots, each one-tenth of an acre.

One plot with no manure. Two plots with Minerals only. Two plots with Nitrogenous manure only. Four plots with Nitrogenous manure and Minerals mixed.	These can be cut by hand and weighed.

One plot unmanured; there should be more, see page 164 (3).

Two long strips manured with minerals only.

Two long strips manured with nitrogenous manures only.

Four larger areas with minerals and nitrogen combined.

The diagram is drawn to a scale of half an inch for a chain. The whole area of the diagram represents about 7 acres. The part shown as under experiment is about 6 acres.

The limit of the plots with combined manure is left undefined on purpose, as the extent might be reduced or extended.

The four corner pieces, as shown, are each about an acre.

In the case of grass experiments, it will be noticed that each corner inside the fence has the same

mixture as the open part of the field out of which it is taken.

In certain districts I think it would be desirable to spread lime over half the area under experiment, because it is supposed to have an important effect on the action of manures. It should be spread some time before the application of the artificial manure.

It would also be easy to vary the form in which each kind of manure is supplied. For instance, the nitrogenous manure might be nitrate of soda on one side of the field, salts of ammonia on the other; or the strength of the dose might be varied. In like manner the form of phosphate might be varied and potash might be tried in addition.

The proposed arrangement is suggested for the following reasons:—

1. To simplify the distribution of manure which would have to be taken right across the field from north to south, for one kind; from east to west for the other, merely omitting a strip in each case.*

2. To enable the occupier to use the reaper or mower as usual, leaving a small central plot to the last.

3. A small portion only of the field will be left without a full supply of the manure presumed to be most profitable, as containing both mineral and nitrogenous ingredients; in fact, about one acre

* The points of the compass are not important; I only use them for convenience to explain the plan on the diagram.

half manured each way, and one-tenth of an acre unmanured; the unmanured plot should be repeated, perhaps by a narrow strip alongside the area under experiment.

4. In the case of experiments on pasture land, I propose that a square plot should be enclosed (with hurdles well fastened together by wire passed through the ends, 6 ft. high,) of three chains each way, nine-tenths of an acre altogether.

The unmanured square (one-tenth) would be the middle of the hurdles; round it would be samples of each of the divisions in the field (one-tenth each), these could be separately mowed by hand and weighed. The results of manures cannot be tested accurately where the animals are grazing. It is obvious that the main object is to fix attention on the action of the two principal elements of manure, nitrogenous and phosphoric, when separate, and when in combination.

These suggestions were submitted in 1885, in the hope that they might lead to concerted action.

I need hardly say how much gratitude I feel to those who have more than realized any expectations which I had formed from experience of the public spirit of those with whom it has been my privilege to be associated for so many years.

CHAPTER XIV.

RECORD OF FIELD EXPERIMENTS, 1885–1890.

The foregoing suggestions were the results of various endeavours to direct attention to questions raised by agricultural experiments, discussed in the volumes of the Bath and West of England 'Journal,' especially those of the Sussex Association for 1884 and subsequent years.

In the year 1885 it was said :*—

"The general and practical conclusion . . . is that it is expedient to take steps in various districts of England to illustrate, exemplify, and test the general principles, a few only of which have been shortly indicated.

"Whether we consider the earlier discoveries of Davy or of Liebig, the continuous patient accumulations of knowledge at Rothamsted and Woburn, or the practical recipes popularised in Sussex, it will be admitted that there is something worth knowing and trying, and ripe for application in practice, if we can but winnow out the grain and blow off the chaff.

* Vol. xvii. p. 237.

"What is now wanted, is not to start new stations for discovery, but experiments on farms for *teaching and testing results.*

"Experiments for discovery require many successive years, and heavy expense. If it were practicable, it might not be desirable to multiply stations for scientific enquiry.

"But, for illustration and general instruction, we need the local interest of practical men—landowners, land agents, land occupiers—carrying on *a real business*," not what is called a model.

In the Report of a Royal Commission it was said :—"The commercial demand for animals and for implements of the best construction is now so great, that any other than an honorary recognition of merit seems to be no longer required." Various suggestions were made by Sir R. Paget, Mr. Sewell Read, and Mr. Jenkins, as to the help which Government might give to Local Societies. It was also suggested that the Universities might be induced to promote endowment for research in connection with Agriculture. This is now under consideration at Cambridge and Oxford, at least so far as the training of teachers is concerned.

On the 28th of April, 1885, "the Council of the Bath and West of England and Southern Counties Society, at a meeting at the Societies of Arts, Viscount Hampden presiding, cordially accepted

the Report of a Committee, of which Mr. Knollys, of Fitzhead Court, in Somerset, was Chairman, and then appointed an Experimental Committee, with instructions to carrying out new objects, in addition to the exhibition of live stock and implements, and specially to establish a system of practical experiments on land, *in ordinary farming condition*, with reference to manures, dairying, and new systems of cultivation, or other efforts which are being made for the profitable cultivation of land."

In the following pages it is proposed to give, in a condensed form, some of the results of the work of the Experimental Committee.

In response to the invitation of the Standing Committee, land was placed at their disposal by the following landowners and tenant farmers in thirteen different counties—Western and Southern.

Western.		*Southern.*	
Somerset	Sir R. H. Paget. Mr. George Gibbons. Mr. C. Norman. Mr. T. Hearn. Mr. Knollys.	Sussex	Viscount Hampden. Mr. W. E. Hubbard.
Somerset, Devon, and Cornwall	Sir T. D. Acland.	Kent	Sir John Lennard. Mr. W. Ashcroft.
Herefordsh.	Mr. Vinor Bonnor. Mr. John Bennett. Lord Ashburton.	Surrey	Mr. Stewart Hodgson.
Shropshire	Mr. John Hill.	Berkshire	Mr. Richard Benyon.
Montgomeryshire	Mr. C. T. Naylor.	Oxfordshire	Mr. S. H. Morrell.
		Hants	Lord Ashburton. Mr. Joshua East.
		Wilts	Mr. Story-Maskelyne, M.P.

Nearly all these gentlemen have continued these experiments to the present time, and more have been added to the list; Hon. Mark Rolle, Sir John Shelley, Sir Gabriel Goldney, Lord Wantage, Professor Wrightson, and several practical farmers on the Chalk lands of Dorset and Hants, also two in Gloucestershire. Such a combination of accurately recorded experience has probably never been published before. It is entirely due to the great exertion of Mr. Knollys, the Chairman of the Committee, and his son. The execution of the work has been inspected under the authority of the Agricultural Department, and its importance has been recognized by a grant of £150.

Experiments on Wheat, 1886. (b. w. s.)*

In the year 1886 Experiments on Wheat were undertaken on 21 farms, with a view to test the effect on the wheat crop of nitrogenous manures and mineral manures combined, in comparison with the effect of either alone, and with the produce of unmanured land. The Experiments were very successfully carried on, and recorded in detail.

The largest rates of increase over the crop on the unmanured plot in five cases were :—

* B. W. S. (Bath, West and South) indicates experiments conducted by the Experimental Committee.—T. D. A., those for which I am responsible.

N

	Rates of Increase, varying from					Average Increase.	
	bush.	lbs.		bush.	lbs.	bush.	lbs.
Nitrate of Soda and Superphosphate . .	6	47	to	15	00	10	24
Sulphate of Ammonia and Superphosphate .	4	17	,,	11	31	7	50
Nitrate alone . . .	3	25	,,	8	43	6	0

The smallest rates of increase in four cases :—

	Rates of Increase, varying from					Average Increase.	
	bush.	lbs.		bush.	lbs.	bush.	lbs.
Nitrate of Soda and Superphosphate . .	2	14		in one case only		2	14
Sulphate of Ammonia and Superphosphate .	1	14	to	5	0	2	3
Nitrate alone . . .	2	14	,,	3	0	1	29

On one of these cases there was no increase at all, except in the straw. *All these cases were after clover* and apparently no manure was needed.

Mr. Knollys gave as the general result of the first year's work—

That the nitrogenous manures (either nitrate of soda or sulphate of ammonia), when combined with mineral superphosphate, had a greater effect than either nitrogenous manure used separately. The use of mineral manure alone was manifestly unprofitable.

I took some pains to classify the cases in three groups according to the apparent fertility of the unmanured land, respectively producing, (1) 5 quarters or more, (2) 4 quarters, (3) less than 4 quarters. I do not wish to trouble the reader with the details; but I may say in a summary form, that—

In the first group, "5 quarters' land," 5 farms, nitrogen with minerals added from 4 bushels to 6 bushels.

In the second group, "4 quarters' land," 6 farms, the nitrogen and minerals gave an increase in three cases of 8 bushels or 10 bushels; nitrogen alone, 7 bushels; superphosphate alone, practically nil. In four of these cases the crop was preceded by clover—in two by folding.

In the third group (natural produce less than 4 quarters) (10 farms, 5 of which cases were after clover, 3 after grass or vetches, 2 after corn crops), the increase due to nitrate and superphosphate was in two cases 10 bushels; on the average of the whole ten farms about 6 bushels.

Another classification was made under the heads of light and heavy soils.

On the light soils the combined manures on 4 farms gave an increase amounting to 8 bushels or more. On the heavy soils the increase on 5 farms averaged over 10 bushels.

Nitrate of soda alone on 4 farms of light soil rose

to 8 bushels, in only one case of heavy soil to the same figure.

Dr. Voelcker assisted the Committee by making a careful examination of all the cases, and by giving critical remarks in detail on each case. These remarks are well worthy of study. His general report was also very valuable, not least because it contained some quotations from a paper written as long ago as 1868 by his father, on "Clover as a Preparation Crop for Wheat."

From the Experiments under consideration, Dr. Voelcker draws these general conclusions among others:

1. That after a good clover crop the application of artificial manures is unnecessary and unprofitable.

2. That after corn crops or fallow, the application of nitrogenous manures is necessary and profitable.

3. That mineral manures alone have practically given no result.

4. Nitrate of soda and sulphate of ammonia have done on the whole better when mixed with mineral superphosphate than when used alone.

One general caution was given. The season was one of unusually high summer-heat. If it had been a wet season, the effect of nitrate of soda might have been very different. In the case of my own farm on good land the experiment was almost a failure, owing to an attack of rust.

Experiments on Barley, 1887 (b. w. s.).

In the year 1887 Experiments on Barley were undertaken. Special attention was given to the effect of potash, in consequence of the remarkable results which had been recorded in the account of the Norfolk Experiments in 1886, as arising from the use of potash.

There was one great improvement in the instructions of the Committee for this year. There were two unmanured plots in different parts of the fields. This duplicate test is most important, as securing a more accurate datum level, to use an engineer's expression.

Thirty offers of land in 14 counties were available. They were classed in 3 groups.

I. After roots drawn from the land.

II. After wheat or other corn crop.

III. On land in any other state requiring manure.

The manures used were :—

<table>
<tr><td>Nitrate of Soda,
1¼ cwt.</td><td rowspan="2">With
Superphosphate,
2 cwt.</td><td rowspan="2">With Muriate
of Potash,
¾ cwt.</td></tr>
<tr><td>Sulphate of Ammonia,
1 cwt.</td></tr>
<tr><td colspan="2">Nitrate of Soda, with Superphosphate,
as above.</td><td>0</td></tr>
<tr><td colspan="3">Guano,
3 cwt.</td></tr>
</table>

The Chairman took a great deal of trouble to have the quality of the barley, as well as the quantity of the produce, in each case estimated, with a view to arrive at a pecuniary balance of profit and loss.

This plan was found open to objections, and was given up afterwards.

It may suffice to state generally that in Group I., after roots removed, the nitrogenous manures *with potash* and the guano by itself showed a slight increase beyond that of nitrogen and superphosphate *without potash.* Group II., after wheat or other corn (undoubtedly, as Mr. Knollys said, the most important), gave some more decided results. If we take an increase of 5 bushels as about balancing the cost of the manure, the cases of increase above 5 bushels may be collected thus:

	Number of Plots.	Increase in Bushels.	
		Varying	Average.
Nitrate, phosphate, potash .	17	from 6 to 14	9
Ammonia, phosphate, potash	18	„ 6 „ 11	8½
Nitrate and phosphate . .	10	„ 6 „ 15	9
Guano	11	„ 6 „ 11	8

Group III. presents no special point of interest.

Dr. Voelcker, in his Report for the year, commends the Committee for having only a few plots, and

those of a practical size, also for raising only a few and important issues. He also points to the advantage of the large range and variety of soils under experiment. Dr. Voelcker strongly prefers the comparison of the actual yield of each plot to an estimated calculation of profit and loss on the quality. Taking Group II. (barley after wheat or other corn) as the most important series, and allowing for doubtful cases, he concludes as follows :—

1. That in this group the application of all the manures except guano has been remunerative.

2. That the results on the whole have not shown any such decided advantage in the use of potash as was found in the Norfolk Experiments of 1886.

The season of 1887 was exceptionally unfavourable for experiments.

The Experiments on Barley for the year 1887 were carried out in duplicate on my home farm. That is, 6 half acres were treated as directed by the Committee ; 6 more half acres adjacent were treated in like manner—swedes had been carted off the 12 plots. This double experiment was useful, as substantially confirming the main result, with sufficient differences in detail to suggest the need for attention to slight causes of variation.

EXPERIMENT ON CONSUMPTION OF ROOTS BEFORE BARLEY, 1887. (T. D. A.)

Adjacent to these 12 plots were 4 quarter-acre plots on which the swedes had been consumed. My steward, Mr. Stevens (to whose intelligent interest in the experiments I am much indebted), and I were desirous to compare accurately the effect of roots *consumed* on the land *without corn*, and *with corn*. We also wished to test the effect of an addition of nitrogenous manure or phosphate in each case. The first result to be noticed is that, whereas the average of the *adjacent* unmanured plots from which roots had been removed was 34 bushels, the average of the plots on which roots were consumed without corn was 52 bushels, showing an increase of 18 bushels due to consumption of roots alone. The increase due to artificial manure on the experimental plots of the Committee was as follows : guano added 10 bushels ; the two mixed manures, with the addition of potash, added respectively 8 bushels and 11 bushels; omitting potash, 6½ bushels.

A second question was whether in the case of consumption of roots *without corn* an addition of a slight top-dressing of nitrate would tell. The answer was a further addition of 5 bushels.

A third question was whether, if roots were consumed *with corn*, it might be worth while to add

a little phosphate, the supposition being that enough nitrogen was supplied by the corn. The answer was an addition of 6 bushels. The addition of corn to roots alone raised the produce 1 bushel, but corn together with superphosphate raised it 6 bushels above roots alone.

Roots and corn gave an increase of 19 bushels; roots, corn and superphosphate, an increase of 24 bushels.

Too much importance must not be given to an experiment on a small scale. But it may not be too much to say that it suggests the expediency of bringing to the test of the balance two important elements in the usual four-course system.

In the 'Journal' * will be found a careful calculation of the cost of the turnip crop and the additional food; but I will not trouble the reader with estimates. We thought that the gain of 12 bushels by manure cost 2*s.* 1*d.* per bushel, the gain of 18 bushels by consumption of roots 4*s.* per bushel; but then something must be allowed for the gain on the value of the sheep, so that the difference might not be great.

The general conclusion from this small experiment may be thus summed up:

1. The consumption of roots on the land produced more than the maximum produce from artificial manure.

* 'Bath and West,' vol. xix., p. 257.

2. The consumption of corn with the roots produced a very slight addition, far below the extra cost.

3. The total cost of the consumption of roots and corn, after allowing for the estimated gain on the sheep, exceeds the cost of the artificial manure.

The effect on succeeding crops of clover and wheat has not been tested.

A further question remains worth consideration, viz., whether after a thorough cleaning for roots, and after consuming them wholly or in part on the land, it may not be practicable and profitable to grow several successive crops of corn in return for a small annual outlay in artificial manure well selected. Some answer to this question was given in the same year 1887 by the growth of barley in another field, the *fourth year* in succession, but this I postpone till I come to 1889, the *sixth year* (see page 182).

Wheat Experiments, 1888. (b. w. s.)

In the year 1888 the Experiments on Wheat were repeated, with some variation—the application of mineral superphosphate by itself was omitted. Special attention was intended to be given to the value of clover; but the season was such as to render the enquiries as to clover of little value.

The Report of the Committee gave the average

result of twenty-four sets of experiments, showing a very slight increase from any of the manures *on the average of the whole twenty-four.* I thought it worth while to examine the details, and I found a number of cases of increase; 12 cases of 6 bushels, 4 of 7, some rising to 8 or 9. I think that when there was such divided evidence of successful application of manures, we may attribute many of the failures to weather and other accidental causes —specially to the washing out of nitrates in a wet season.

It must be borne in mind that the object of these combined experiments is not to take a plebiscite or mass vote for or against nitrogen and phosphates —the value of either or both, when properly used, may be taken to be a settled question—or even as to the relative value of nitrate or ammonia.

What we have been aiming at is to test the application of admitted principles to different soils, different crops, and different rotations. For this end we desire to awaken a wide interest among a number of intelligent practical men in the proper way of arriving at conclusions, and especially we need to enquire into the causes of comparative failure in particular cases.

EXPERIMENTS ON OATS IN A HILLY COUNTRY.

(T. D. A.)

In this year, 1888, a most successful Experiment on the Oat crop was undertaken on Winsford Hill, a spur of Exmoor, at a height of 1000 feet above the sea. It was carried out on three farms by a Committee of intelligent young men, under the guidance of a tenant farmer of wide experience as a valuer, Mr. Amos Lovelace. Some mistakes occurred on two of the farms, but Mr. Lovelace's experiment on his own farm was a model.

The manures were applied on a plan like that suggested by me at page 162, of crossing phosphates with nitrogenous manures.

I will not trouble the reader with the detail fully set out in the 'Journal,' 1888.* The plan provided four plots with sulphate of ammonia alone—two plots with nitrate of soda alone—two plots with sulphate of ammonia and phosphate—two plots with nitrate and phosphate—four plots with no manure. The smallest plots were one-eighth of an acre, twenty perches. It is obvious that by this arrangement there was a considerable safeguard against accidental variations.

The following table will show at a glance the remarkable influence of phosphate. The hill country near Winsford is a breeding district; a

* 'Bath and West,' vol. xx., p. 258.

considerable quantity of phosphate walks to market in the form of store stock, and the soil on the hills is shallow. Lime is locally considered most important; its effect on pasture cannot be doubted.

	Grain.		Incr. + Decr. −		Straw.	Incr. + Decr. −
	bus.	lbs.	bus.	lbs.	lbs.	
No Manures	41	23	..		3·011	..
Sulphate of Ammonia	40	0	− 1	23	3·238	+197
Nitrate of Soda	40	7	− 1	11	3·296	+255
Superphosphate	49	32	+ 8	9	3·088	+ 47
Sulphate of Ammonia and Phosphate	60	0	+18	17	3·854	+813
Nitrate of Soda and Phosphate	58	12	+16	29	3·904	+863

The oats were sown, 1888, on a high open field, after 4 years' grass. The grass had been seeded, 1883, after roots fed on the land, without a corn crop, according to the excellent practice of our best hill farmers, or as we might call them, in a double sense, high farmers.

EXPERIMENT ON OATS ON POOR CLAY. (T. D. A.)

Another experiment on Oats was tried in East Cornwall on the very poor Clays between Dartmoor and Bude—not worth much more than 5*s.* per acre. The average produce of two unmanured plots was 21 bushels per acre; by spending £1 1*s.* per acre in nitrate and phosphate the produce was doubled. The same sum spent in sulphate of ammonia and phosphate resulted in a greater gain, viz., 26 bushels and 980 lbs. of straw, which, after deducting the cost of manure, leaves a gain of £2 2*s.* per acre. Nitrate of soda alone and sulphate of ammonia alone did not produce enough to pay for the manure;

wherever phosphate was applied, Dutch clover came up abundantly.

I have not thought it necessary in each case of the Experiments of the Bath and West Committee on Corn to insert the exact amount and cost of each manure used.

It may suffice to say that 1 cwt. per acre of sulphate of ammonia, 1¼ cwt. of nitrate of soda, and 3 cwt. of superphosphate have been the quantities used every year except in 1887 and 1889, when the quantity of superphosphate was reduced to 2 cwt. in consequence of the use of ¾ of a cwt. of muriate of potash. It is not far from the mark to say that the cost of the manures for corn crops was about 25*s.* per acre, in some cases 21*s.*

Barley Experiments at Killerton (T. D. A.),

Showing the effect of Manure on the Corn crop for six successive years.

I may now, without going into much detail, refer to a steady course of Experiments on Barley, begun on my farm in 1885, and continued for six years; as they have a direct bearing on the course of combined experiments carried on by the Bath and West of England Society.

The barley was grown on a field of strong land, not heavy clay, but reputed as good wheat-land. The crop of 1884 had been wheat; that of 1883 mangold, all carted off. The field was therefore not in high condition in 1885. The plots were each one acre.

The produce in 1885 on an unmanured Plot was	32	bushels.
" with 3 cwt. of Superphosphate,	32	"
" " 1½ cwt. of Superphosphate, 1 cwt. of Nitrate of Soda,	36	"
" " 1½ cwt. of Nitrate of Soda,	43	"

In the year 1887 the four acre-plots were each divided into two half-acre plots; four half acres were carried on with the same manures as before; on three of the other four half acres potash was added; on one half acre the dose of nitrate of soda alone was doubled, without any other manure.

The objects of these Experiments were to find out; 1st, whether a course of corn crops in successive years could be grown without injury to the land and with a profit; 2nd, to test the question whether nitrate of soda is (as commonly asserted) an exhausting manure.

The natural produce of the field in 1887 (not in high condition to start with in 1884), after four successive corn crops was 23 bushels per acre.

The application for the third year in succession of 1½ cwt. of superphosphate per half acre (3 cwt. per acre) added only 1½ bushels per acre.

Nitrate of soda, 1 cwt., with superphosphate, $1\frac{1}{2}$, added 6 bushels per acre.

Nitrate of soda, with superphosphate and potash, added 12 bushels.

The same mixture, omitting superphosphate, added $10\frac{1}{2}$ bushels.

But a *double dose of nitrate* of soda (3 cwt. per acre), added 14 bushels. The addition of straw in this last case was very great, double that of the unmanured plot.

The result seems very favourable to the value of nitrate of soda, even without any minerals; the increase due to the addition of potash, even on strong land, deserves notice.

The Experiments on Barley were repeated in 1888 for *the fifth year in succession*. The natural produce (unmanured) was then reduced to 16 bushels per acre.

I will not trouble the reader with a repetition of all the details, suffice it to note the following results :—

1. Superphosphate alone produced nil.

2. All the mixtures of nitrate of soda (with superphosphate and potash, either singly or both together) produced an increase, varying from 6 bushels to 12 bushels per acre.

3. The application of $1\frac{1}{2}$ cwt. of nitrate of soda alone produced an addition of nearly 10 bushels per acre. The application to a contiguous plot of

a double dose of nitrate of soda produced an addition of more than 16 bushels per acre and 1100 lbs. of straw.

It will be observed that the yield is not a heavy one; but the season was not favourable, and the land is not the most suitable for barley. I hope I do not seem to attach too much importance to this small experiment, though continued for five years, always pointing to the same conclusion.

The Experiment on Barley was repeated for the sixth corn crop in 1889. It may be worth while to give the result of this final experiment in a tabular form (see page 186), that the details may be examined critically.

It was shown by the experiments of the 5th year that the land had by continuous corn growing become foul. It was therefore decided to drill the 6th year's crop of barley about 10 inches between the rows of corn, so as to admit of hand hoeing.

This was done, and although much of the weed was destroyed, much remained in the rows of corn which could not be hoed or even pulled out without at the same time destroying some of the corn.

The natural produce of the field after six years' successive corn crop was about $14\frac{1}{4}$ bushels per acre, as shown in plot 5.

Superphosphate alone (plot 3) as before had but

little effect, this year giving a gain of $1\frac{1}{2}$ bushels of grain, and a loss in straw of 30 lbs.

KILLERTON HOME FARM (BLACKWELL FIELD).

Plot = half Acre.	Manure of the half Acre.	Produce of each half Acre.						Increase per Acre.		
		Head Corn.		Tail Corn.		Weight per Bushel.	Straw.	Head Corn.		Straw.
	lbs.	bus.	lbs.	bus.	lbs.	lbs.	lbs.	bus.	lbs.	lbs.
1	Nitrate Soda 84	9	36	0	37	49½	680	+ 7	0	+436
2	Nitrate Soda 168	15	16	0	48	48½	911	+18	10	+898
3	Superphosphate .. 168	7	0	1	6	51	447	+ 1	29	− 30
4	Superphosphate .. 168 Nitrate Soda .. .. 84 Muriate Potash .. 56	11	9	0	41	49½	818	+ 9	45	+712
5	Nil	6	11	0	46	51	462	..		..
6	Nitrate Soda .. .. 84 Muriate Potash .. 56	8	29	1	13	51½	708	+ 4	36	+492
7	Nitrate Soda .. .. 56 Superphosphate .. 84	8	10	0	51	51½	556	+ 3	49	+188
8	Nitrate Soda .. .. 56 Muriate Potash .. 56 Superphosphate .. 84	5	25	0	31	51½	508	− 1	23	+ 92

Remarks :—Barley sown April 3rd.

Superphosphate distributed before drill, and harrowed in.

Muriate of potash distributed after drill, and harrowed in.

Nitrate of soda distributed April 30th.

The "double dose" of nitrate of soda = 3 cwt. an acre (plot 2), showed this year a gain of 18¼ bushels of corn, and 898 lbs. of straw, being equal in money value to, say 3*l.* 10*s.*, taking the corn at 3*s.* 6*d.* per bushel, and the straw at 1*l.* per ton.

From this sum, if we deduct cost of manure = 1*l.* 10*s.*, we have a clear gain of 2*l.* an acre, being the same result as that obtained in the previous year.

Plot 8 — an outside plot—was again much damaged by rooks and game, which perhaps chiefly accounts for its small yield.

It will be understood that drilling the barley 10 inches between the rows and hoeing, &c., rather tended to lessen the yield of corn.

The chief practical conclusion, as it seems to me, to be drawn from these experiments for six years, is the effect of manure, especially nitrogenous manure, in keeping down weeds. To all appearance the field was clean and in good condition when we began.

One of my practical neighbours gave me a caution three years ago, that I was exhausting the land with nitrate of soda; "We will see about that," was the reply. So we doubled the dose of nitrate for two successive years on plot 2; that is the one plot which showed a decided increase with profit. The unmanured plot 5, and the plot 3 with super-

phosphate alone, were smothered with weeds from sheer poverty or want of nitrogenous food.

These weeds must have been long lying in the land, as it had been for many years well farmed before I took it in hand about fifteen years ago. The weeds were not due to exhaustion of soil by over-tilling, or want of rest, but to want of proper food for the crop. When the crop was well fed, it took the lead, and weeds were absent.

Of course it is admitted that nitrate alone must not go on for ever if other elements are deficient in the soil. The soil in this case is a rich arable loam.

It may be hoped that we are all learning something, and that our experiments are tending to bring knowledge home to the practical man; but we want many more co-operators.

This attempt to solve some important questions seems to point further to another conclusion, when it is compared with the effect on the barley crop of consuming roots with or without corn, or artificial manure as reported on page 176.

Is it not probable that after a thorough cleaning with a root crop, we may find out *the proper elements of purchased manure*, by which at a moderate cost we may grow successive corn crops on suitable land for several years?

As the land required cleaning last year, 1890,

we did not repeat the barley crop ; but we grew a fair lot of turnips with 4 cwt. of superphosphate; there was not much apparent difference between the plots where the nitrogenous food had been applied or withheld in former years.

We have now, 1891, a promising wheat crop, and though I cannot look forward to many more crops in my time, I hope that the field may continue to supply some further useful information to my neighbours.

Grass Experiments at Killerton.

Experiments on grass, especially on old pasture, are much needed. But they are extremely difficult to carry on with any practical result. We have had many accounts given by seedsmen ; and by some Societies, especially by the Manchester and Liverpool Society in Cheshire, on individual grasses or special mixtures ; and their respective nutritive values have also been reported on by chemists. But we do not make much advance in any enquiry which will help the practical farmer on existing pastures. It must never be forgotten that grasses, on meadows, or pastures, as I have already said, page 155, grow in company ; there is a struggle among them which does not always end in the survival of the fittest, but generally in what the practical man calls going back to the natural

grasses. In the West of England, especially in the hilly breeding district bordering on Exmoor, the conviction of the benefit of lime, or rather lime and earth, outweighs all the opinions based on theory.

In recent years the opinion has gained ground that it is wise to spread dung on pasture, and not to apply it all to the tillage land. And there seems little doubt that the consumption of cake on grass by sheep, which are better manure distributors than cattle, is wise expenditure and real economy.

I have carried out a small experiment for five years on old pasture, divided into plots of one square chain each (a tenth of an acre), so that an additional cwt. represents half a ton per acre. The pasture is part of an old deer park, for the last fifty years and more grazed by sheep and cattle—never mown.

Mineral manures were applied from east to west, nitrogenous manures were applied from north to south, so that there were duplicate plots with each of those manures alone, and four plots with the two kinds of manure combined. Each plot was mown and weighed separately.

The experiment hardly shows any decided advantage resulting from artificial manures. The unmanured plots produce about 4 cwt. per plot, or two tons per acre. The minerals alone show a very

slight increase. Dissolved bones and the mixture of sulphate of ammonia, or of nitrate of soda with phosphate, yielded about half a ton increase.

But we have noticed every year the tendency of ammoniacal manure to increase the coarser grasses, and the strong overgrowth of the Holcus or Yorkshire fog, and of cocksfoot, but specially the entire extinction of rye-grass.* Little advance has been made in experiments on grass beyond the information to be gathered from the grass parks at Rothamsted, so well described by Mr. Maxwell Masters in his 'Plant Life on the Farm,' in the chapter called "the Battle of Life."

It was desired by the Experimental Committee of the Bath and West of England Society to set on foot some Experiments on Pasture—fed, not mown. We wished to have three fields or enclosures by rail; one to have no manure, a second to have a specially-arranged manure, say Sir H. Thompson's mixture of nitrate, phosphate and potash; a third to be fed with cake. Of course the amount of increased live-weight of cattle was to be compared, and also the effect of the cake and artificial manure was to be tested in the following year; but the expense and the difficulty of making the arrangement obliged the Committee to postpone the attempt.

* This year, 1891, I have noticed a few plants of rye.

Experiments on Barley, 1889 (b. w. s.).

The Field Experiments of the Experimental Committee in the year 1889 were on Barley after Wheat; they were in the main a repetition of those of 1887; but no attempt was made to show the result in money value. The returns of produce were of a more level character than before.

It was intended to give a second trial to potash when added to nitrate and superphosphate—the addition of 3 cwt. of salt instead of potash was also tested.

The potash gave some increase, but not enough to pay for its cost. The addition of salt was decidedly beneficial.

The nitrogenous manures combined with superphosphate alone, gave in almost every case an increase of marketable barley, without taking into account tail corn, or straw. With the addition of salt they have shown a very profitable increase. Dr. Voelcker, being in India, was unable to give us the advantage of his remarks on this year's work.

Experiments on Mangold, 1890 (b. w. s.).

The Field Experiments of the Experimental Committee in 1890 had, for their general object, to find out the best manures for a good crop of man-

gold, having regard to their effect on a succeeding crop of corn.

The special objects (not to go into full detail) were to ascertain the effect, (1) of a full dressing of dung alone; (2) of a full dressing of dung, aided by superphosphate; (3) of a half dressing of dung, with nitrate alone; (4) or aided by superphosphate, or by salt—(6 plots were so arranged), 6 other plots were manured with artificials alone, and no dung.

Mr. Knollys gives two very useful tables showing the cost per ton of the increase gained, much to the advantage of the plots without dung. Four plots with nitrate of soda gave a large increase, at a cost varying from 3*s.* 1*d.* to 4*s.* 7*d.*, while the cost of the increase on the dunged plots ranged from 6*s.* per ton to 11*s.* 9*d.*

The Experiments, therefore, point very forcibly, so far as the mangold crop is concerned, to the advantage which artificial manures in proper combinations, either by themselves or with small quantities of dung, have over large and heavy dressings of dung.

But we have yet to see what will be the effect upon the succeeding corn crop; until we learn this, our experiment is incomplete.*

* I may mention that on my farm the whole crop was weighed, not only sample perches. The whole was completed in 8 hours; 135 cartloads passed over the weigh-bridge, each taking on an average 3½ minutes; this was owing to Mr. Stevens' good management and interest in the work—

The plots were admirably arranged by Mr. Knollys, a roadway passing between the plots having dung, and those not having it. I cannot do better than give Mr. Knollys' statement of the total result.

Taking the average of twenty-three stations, the result in order of merit is as follows :—

	Tons	cwt.
1. Nit. of Soda, 4 cwt.; Superphos., 4 cwt.; Salt, 4 cwt. ..	29	0
2. Nit. of Soda, 2 cwt.; Superphos., 4 cwt.; Salt, 4 cwt. ..	27	0
3. Dung, 10 loads; Nit. of Soda, 2 cwt.; Salt, 4 cwt... ..	26	18
4. Nit. of Soda, 4 cwt.; Superphos., 4 cwt.	26	12
5. Dung, 10 loads; Nit. of Soda, 2 cwt.; Superphos., 2 cwt.	26	7
6. Dung, 10 loads; Nit. of Soda, 2 cwt...	25	7
7. Nit. of Soda, 4 cwt.	24	14
8. Dung, 20 loads; Superphos., 4 cwt.	24	10
9. Sulph. Ammonia, 3 cwts.; Superphos., 4 cwt.	24	6
10. Dung, 20 loads	23	10
Average of Unmanured plots	15	14

I have omitted the lbs., treating 84 lbs. or more as 1 cwt.

"From this it will be seen that the three salt plots stand at the head of the list, and No. 10, with 20 loads of dung, at the bottom."

It may be observed, in addition, that nitrate of soda was supplied to the whole of the seven first plots of the list.

I may conclude this account of the Experiments by quoting Mr. Knollys' reference to the late Dr. Voelcker's cautions against relying upon single

really the horse and manual labour was no more than would have been required to store the crop for winter use near the feeding-sheds. I mention this to show that experiments are not necessarily expensive.

experiments, and the expression of his wish for a large number of field experiments, conducted in different localities by practical men. Mr. Knollys adds : "How his heart would have been gladdened if he could have seen our present Bath and West of England work." I heartily join in this feeling, only adding how warmly grateful he would have been to Mr. Knollys.

APPENDIX.

(*Referred to, Chapter I. p.* 14.)

The Extracts which follow are taken from Professor Asa Gray's 'Lessons on the Elements of Botany for Beginners.' He says that these "simple outlines of the anatomy and physiology of plants were intended for the better preparation of students in systematic Botany, and to give to all learners some general idea of the life, growth, intimate structure, and action, of the beings which compose so large a part of organic nature."

I have taken the liberty to reprint them for the practical farmer for whom this book is intended, because they are the simple utterance of a great man, and appear to me to gather up into a connected whole a number of details, which I have endeavoured in a homely way to state in reference to Agriculture.

Before we proceed to the extracts it may be allowable to illustrate some technical words in addition to those already explained.

We have in Agriculture to deal with organized matter in three states. 1. *Active life*; 2. *passive*

changes, some mechanical, some chemical, which take place in living bodies; 3. *decay and ultimate decomposition*, or return to inorganic elements. With reference to these three states of matter, words derived from the Greek language are used in all botanical works.

1. *Plasma* means "formative matter." The words *Protoplasm* or *Bioplasm* are used to define the basis of active physical life, both in plants and animals. (See p. 14.)

2. Protoplasm is in the form of *Cells*, contained in cell walls ('Cellulose,' p. 68). Cell walls are not active, but when new cells are produced and built up in contact they form what is called in English a *tissue*, such as is to be found in leaves, or in wood, or, to take an extreme case, in the bark of a cork-tree. For these tissues the word "*enchyma*," meaning "fusion," is used in composition, in "par-enchyma," "pros-enchyma." and other compound words, according to the position of the cells in the tissue.

3. When the life of a plant is at an end there ensues a process of decay. The decay of animal matter is called putrefaction. But there is a gradual change of organized matter to which Liebig gave the name *Eremacausis* (*erema*, by degrees; *causis*, burning, whence *caustic.*) The conversion of woody matter, Liebig says, into humus is of this nature.

It is obvious that these three conditions of matter have a most direct bearing on the Chemistry of Farming and on practical Agriculture.

The extracts which follow are taken almost verbatim from Asa Gray's work, the only variation being the omission of a few phrases or words, generally indicated by the printer's marks. The paragraphs from which they are taken are numbered, as the arrangement is slightly altered.*

EXTRACTS FROM ASA GRAY'S BOTANY.

§ 394. "**Growth** *is the increase of living things in size and substance.* It appears so natural that plants and animals should grow, that one rarely thinks of it as requiring explanation. . . .

§ 395. "Although observation may show that a seed or seedling weighing only two or three grains may double its bulk and weight every week of its early growth, and in time produce a huge amount of vegetable matter, it is still to be asked what this vegetable matter is, where it came from, and by what means plants are able to increase and accumulate, and build it up into the fabric of herbs and shrubs and lofty trees.

§ 386. "**Protoplasm.** All this fabric was built

* The marks [ ] contain references to former pages in the present volume; or indicate that some of the sentences are not quotations.

up under life, but only a small portion of it is at any one time alive. As growth proceeds, life is passed on from the old to the new parts, much as it as been passed on from parent to offspring, from generation to generation in unbroken continuity.

§ 396. "*Protoplasm* is the common name of the plant stuff in which life essentially resides.

"All growth depends upon it, for it has the peculiar power of growing and multiplying and building up a living structure—the animal no less than the vegetable structure, for it is essentially the same in both.

"Indeed all the animal protoplasm comes primarily from the vegetable which has the prerogative of producing it, and the protoplasm of plants furnishes all that portion of the food of animals which forms this flesh and living fabric."

Dr. Maxwell Masters ('Plant Life on the Farm'), speaks of this marvellous substance as a viscid colourless, jelly-like substance. "Without it, or when it is dead, the plant is dead too; with it, the plant lives, without, it dies." "Suffice it," he says, "to call it as Huxley does, *the physical basis of life.* With few exceptions it does not exist in one unbroken mass. Each living cell consists essentially of a certain proportion of protoplasm contained within a membranous bag or bladder," an envelope technically called the cell wall.

PLANT FOOD AND ASSIMILATION.

§ 445. "Only plants are capable of originating the materials which compose the structure of vegetables and animals. The essential and peculiar work of plants is to take up portions of earth and air (water belonging to both), upon which animals cannot live at all, and to convert them into something organizable; that is, into something that, under life, may be built up into vegetable and animal structures. All the food of animals is produced by plants. Animals live upon vegetables directly or at second hand, the carnivorous upon the herbivorous, and vegetables live upon earth and air, immediately or at second hand.

§ 446. "The food of plants, then, primarily, is earth and air. This is evident enough from the way they live. Many plants will flourish in fine sand, or on the bare face of a rock or wall, watered merely with rain. Almost any plant may be made to grow from the seed in moist sand, and increase its weight many times, even if it will not come to perfection. . .

§ 447. "It is true that fast-growing plants, or those which produce much vegetable matter in one season (especially in such concentrated forms as to be useful as food for man or the higher animals), will come to maturity only in an enriched soil. *But what is a rich soil?* One which contains decom-

posing vegetable matter, or some decomposing animal matter, that is, in either case, some decomposing organic matter formerly produced by plants. Aided by this, grain-bearing and other important vegetables will grow more rapidly and vigorously, and make a greater amount of nourishing matter than they could if left to do the whole work at once from the beginning. So that in these cases also all the organic or organizable matter was made by plants, and made out of *earth and air.* For the larger and most essential part was *air and water.*

§ 448. "Two kinds of material are taken in and used by plants :—

"*The essential constituents* of the organic fabric are those which are dissipated into air and vapour in complete burning. They make up from 88 to 99 per cent. of the leaf or stem, and essentially the whole, both of the *cellulose* of the walls and the protoplasm of the contents.

"*The Chemical Elements of the cell walls or cellulose* [p. 68], as also of starch, sugar, and all that class of organizable cell-material, are *carbon, hydrogen*, and *oxygen* [p. 32]. The same with nitrogen are the constituents of *protoplasm, or the truly vital part of vegetation.*

"*Earthy constituents*, those which are left in the form of ashes when a leaf or a stick of wood is burned in the open air. These consist of some potash (or soda in a marine plant), some silex (the

same as flint), and a little lime, alumine or magnesia, iron or manganese, sulphur, phosphorus, &c. — some or all of these in variable, and usually minute proportions. They are such materials *as happen to be dissolved, in small quantity* in the *water* taken up by the roots, and when *that* is consumed by the plant, or flies off pure (as it largely does) by exhalation, the earthy matter is left behind in the cells—just as it is left incrusting the sides of a tea-kettle, in which much hard water has been boiled.

§ 449. "The **Chemical** *Elements* out of which organic matters are composed are supplied to the plant by *water*, *carbonic acid*, and some combination of *nitrogen*.

"*Water*, far more largely than anything else, is imbibed by the roots, also more or less by the foliage in the form of vapour. Water consists of oxygen and hydrogen; and cellulose or plant wall, starch, sugar, &c. (however different in their qualities), agree in containing these two elements in the same relative proportions as in water [p. 67].

"**Carbonic-acid-gas** (carbon-dioxide), is one of the components of the atmosphere—a small one, ordinarily only about $\frac{1}{2500}$ of its bulk, sufficient for the supply of vegetation, but not enough to be injurious to animals as it would be if accumulated. Every current or breeze of air brings to the leaves expanded in it a succession of fresh atoms (or mole-

cules) of carbonic acid which it absorbs through its . . . breathing-pores. This gas is also taken up by water. So it is brought to the ground by rain, and is absorbed by the roots of plants, either as dissolved in the water they imbibe, or in the form of gas in the interstices of the soil . . . whence the roots of the growing crop absorb it.

"**Nitrogen** . . . is brought into the foliage and also to the roots . . . in the same way as carbonic acid.

"The nitrogen which, mixed with oxygen, a little carbonic acid, and vapour of water, constitutes the air we breathe, is the source of this plant element. . . . But it is very doubtful, if ordinary plants can use any nitrogen gas directly as food, that is, if they can directly cause it to combine with the other elements so as to form protoplasm.

"But when nitrogen is combined with hydrogen (forming ammonia), or when it is combined with oxygen, forming nitric acid and nitrates, plants appropriate it with avidity. And several natural processes are going on in which the nitrogen of the air is so combined and supplied to the soil in forms directly available to the plant.

"The most efficient is *nitrification*, the formation of nitre (nitrate of potash) in the soils, especially in all fertile soils, through the action of a bacterial ferment."

Assimilation.

[Besides the growth of plants as visible to the unaided eye, there are changes going on inside the tissues of the plant, or the cell-walls, or cellulose, which is essentially the same in the stem of a delicate leaf or petal, as in the wood of an oak, except that the walls are thickened. These changes are now included under the technical word *Metabolism*, which takes the place of *Assimilation.*] *

§ 406. "All the soft cellular tissue, like that of leaves, that of pith and of the green bark, is called *Parenchyma*, while fibrous and woody parts are composed of *prosenchyma*, that is, of partially transformed strengthening cells.

§ 409. "The proper cellular tissue or parenchyma is the ground-work of root-stem and leaves; this is traversed . . . by the strengthening tissue . . . in the form of bundles and threads. . . . These extend into and ramify in the leaves spreading out . . . as a framework of ribs and veins, which supports the softer cellular portion or parenchyma."

Cell Contents.

§ 414. "The living contents of young and active cells are mainly protoplasm, with water or watery sap which this has imbibed. All the various products which plants elaborate, . . . out of the common

* *See* Note, p. 208.

food which they derive from the soil and the air, are contained in the cells, and in the cells they are produced.

§ 415. "Sap is a general name for these liquid contents.

§ 416. "Among the solid matters into which cells convert some of the sap, two are most important, viz., chlorophyll and starch.

§ 417. "**Chlorophyll** meaning *leaf green* . . . consists of soft grains . . . partly wax-like, partly protoplasmic. Chlorophyll is essential to ordinary assimilation in plants ; by its means, under the influence of sunlight, the plant converts crude sap into vegetable matter.

§ 418. "The permanent fabric of plants is called cellulose ; in its soluble form it is sugar ; in a less soluble form it is dextrine, a kind of liquefied starch in the form of solid grains. Stored up in the cells it is starch."

[Many changes take place in the plant in different stages of its growth and its approach to ripeness or maturity. See Amides, p. 74.]

§ 450. "Only plants are capable of converting mineral into organizable matters, and this all-important work of these changes is done by the plants, so far as all ordinary vegetation is concerned, only

§ 451. "*Under the light of the sun acting upon green part or foliage*, that is, upon the chlorophyll,

or upon what answers to chlorophyll which these parts contain. The sun in some way supplies a power which enables the living plant to originate these peculiar chemical combinations to organize matter into forms which are alone capable of being endowed with life. . . ."

[This may be shown by very simple experiments. It is only in sunshine or bright daylight that green parts or plants give out oxygen gas—then they regularly do so.]

" Leaves are so many workshops full of machinery worked by sun-power."

§ 452. " All this oxygen gas given off comes from the decomposition of the carbonic acid [carbon dioxide] taken in by the plant. For cellulose and also starch, dextrine, sugar, and the like are composed of carbon along with oxygen and hydrogen in just the proportion which form water. The carbonic acid and water taken in, less the oxygen, which the carbon brought with it as carbonic acid, and which is given off from the foliage in sunshine, just represents the manufactured article **Cellulose.**

§ 453. " It comes to the same if the first product of assimilation is sugar or dextrine, which is a sort of soluble starch, or starch itself. In the plant all these forms are readily changed into one another. In the tiny seedling, as fast as this assimilated matter is formed, it is used in growth, that is, in the formation of cell walls ; after a time some or much

of the product may be accumulated in store for future growth, as in the root of the turnip or the tuber of the potato, or the seed of corn or pulse. The store is mainly in the form of starch. When growth begins again, the starch is turned into dextrine, or into sugar in liquid form, and used to nourish and build up the germinating embryo or the new shoot, when it is at length converted into cellulose and used to build up plant structure.

§ 454. "But that which builds plant fabric is not the cellular structure itself, the work is done by the living protoplasm which dwells within the walls.

"Protoplasm assimilates, along with the other three elements, the nitrogen of the plant's food. This comes primarily from the vast stock in the atmosphere, but mainly through the earth, where it is accumulated through various processes in a fertile soil,—mainly so far as concerns *crops* from the decomposition of former vegetables and animals. This *protoplasm*, which is formed at the same time as the simpler cellulose, is *essentially the same as the flesh of animals* and the source of it. It is the common basis of vegetable and animal life.

§ 455. "*So plant assimilation produces all the food and fabric of animals.* Starch, sugar, the oils (which are, as it were, these farinaceous matters more deoxidated), chlorophyll, and the like, and even cellulose itself, form the food of herbivorous

animals and much of the food of man. When digested, they enter into the blood, undergo various transformations, and are at length decomposed into carbonic acid and water, and exhaled from the lungs in respiration—in other words, are given back to the air by the animals as the very same materials which the plant took from the air as its food—are given back to the air in the same form that they would have taken if the vegetable matter had been left to decay where it grew, or if it had been set on fire and burned, and with the same result, too, as to the heat—the heat in this case producing and maintaining the proper temperature of the animal."

NOTE *on Metabolism in Animals.*

[Changes are constantly going on in the animal organisms which are included under the general term "metabolism," referred to p. 204, and now in common use.

Food is thus incorporated by digestion, and oxygen by breathing. This is called assimilation, or constructive metabolism. Various secretions are given from the bowels, the kidneys, the skin, and the lungs. This is called destructive metabolism. (Landois and Stirling (Chapter vii.) on the "Metabolic Phenomena of the Body.")

These gradual changes from the germ cell through infancy to maturity, and thence through decay to death and decomposition, have been the subject of profound study in modern times, especially in organic chemistry.

The results of these investigations are of the utmost importance to the Farmer, in reference to the breeding and feeding of Live Stock. But they require much sound judgment and experience in turning them to practical account.]

APPENDIX II.

In the reference to Asa Gray's 'Elements of Botany,' and in connection with the extracts from that most interesting volume, the names of Darwin and Huxley have been mentioned. The teaching of those eminent writers, on the origin and development of species, and on the basis of physical life, cannot be overlooked in dealing with the education of the rising generation if they are to understand the principles of modern Science which bear on vegetables and animals.

If I conclude this small attempt to show the connection between Agriculture and Science by quoting some extracts from another volume by Asa Gray on 'Natural Science and Religion,' I hope to be excused by those critics who consider that there is no proper connection between the two subjects. At any rate in this, my last endeavour to assist my young friends, I am acting on what I believe to be a serious duty to them and their families.

Not many years before his lamented death Asa Gray delivered two lectures to the Theological School of Yale College, in compliance with a special

invitation. He began by saying, "While listening weekly, I hope with edification, to the sermons which it is my privilege and duty to hear, it has now and then occurred to me that it might be well if an occasional discourse could be addressed from the pews to the pulpit."

The first lecture on "Scientific beliefs" is, in the opinion of competent judges, a most masterly sketch of the changes which have occurred within the last half century.*

He begins by referring to the complete change of view as to the distinctness of the animal and vegetable kingdom.

It was once implicitly supposed that every living thing was distinctively either plant or animal.†

Modern science has established "that the component material, the protoplasm, is essentially the same in both." "Each ordinary plant or animal begins as one cell, which is then the simple individual." The doctrine of cells belongs wholly to the Biological Science of the last half century. But its full bearing on the relation between vegetable and animal life is more recent.‡

He passes from the consideration of the *two kingdoms* to the questions relating to the *succession of species and individuals.* He says that when he began to read scientific works "the commonly

* p. 9. † p. 11. ‡ p. 30.

received doctrine was that the earth had been repeatedly depopulated and repopulated over and over again," and that "the species which now with man occupy the present surface of the earth belong to an ultimate and independent creation." "This view, as a rounded whole and in all its essential elements, has very recently disappeared from Science. It died a royal death with Agassiz, who maintained it with all his great ability as long as it was tenable. I am not aware that it now has any scientific upholder. It is certain that there has been no absolute severance of the present from the nearer past." *

From the question of the new or, so to speak, intermittent creation of species, Asa Gray goes on to deal with the fixity or variability of species. On this, also, scientific opinion is not what it was thirty or forty years ago.

"There is now a different attitude toward this class of questions," "The absoluteness of species is no longer taken for granted." †

Agassiz took the ground that all marked stable forms were species, and therefore original creatures. Herbert, the Dean of Manchester, sixty years ago "announced his conviction that botanical species are only a higher kind of varieties." Dr. Wells, the sagacious author of the 'Theory of Dew,' hit on

* p. 35. † p. 39.

the idea of natural selection, while resident in America. "All animals vary more or less. Agriculturists improve domesticated animals by selection. What is done by Art, is done with equal efficacy though more slowly by Nature." *

So far Asa Gray agrees with Darwin. Change of species is a fact—natural [or other] selection is a fact. But he adds—

"The point I wish to make . . . is, that *natural selection* — however you expand its meaning — cannot be invoked *as the cause* of that upon which it operates, *i.e.* variation." "If by natural selection is meant . . . all the known or unknown causes" at work "in organic nature," . . . "it is like saying that whatever happens is the cause of whatever comes to pass." †

"Man, while on the one side a wholly exceptional being, is, on the other, an object of natural history—a part of the animal kingdom." ‡

"Man, in short, is a partaker of the natural as well as of the spiritual. And the Evolutionist may say with the Apostle, 'Howbeit that was not first which is spiritual, but that which is natural; and afterward that which is spiritual.' Man 'formed of the dust of the ground' endowed with 'the breath of life' 'became a living soul.' Is there any warrant for affirming that these processes were instantaneous?" §

* p. 43. † p. 49. ‡ p. 54. § p. 55.

It would hardly be consistent with the purpose of this volume to introduce even a faint tracing of the well-balanced parallel, which so great a student of Nature as Asa Gray exhibits, between the progress of *scientific belief* and the changes of *modern thought* in regard to religious documentary records. He refers to great thinkers in former days, such as Augustine and Thomas Aquinas, Leibnitz and Newton, to Dr. Mozley and Lord Blachford, and to Mr. Arthur Balfour among other modern writers.

A few extracts from the second lecture will at least be suggestive of the spirit of true scientific enquiry at the present time.

"I have used the phrase 'Scientific belief' as the one best suited to the occasion. The term is elastic, covering many degrees of conviction or assent, from moral certainly to probable opinion. In this respect, scientific and theological beliefs are similar, as they are also in being mainly states of mind towards that which is incapable of demonstration. . . . Much also is, or should be, held under suspense of judgment, a state of mind eminently favourable to accurate investigation." *

[Asa Gray accepts the doctrine of the Evolution of species as one which has taken its place among scientific beliefs (generally, not universally); his own

* p. 58.

conviction is clear that it is not inconsistent with religious belief, that it may be taken as a true account of the course of nature as a fact.]

"As to variation, *that really occurs as a fact,* though we know not how; and if we frame explanations of the causes of the variations of living things, still we probably shall never be able to carry our knowledge very much further back, for in each variation lies hidden *the mystery of a beginning.*" *

He does not admit that the *fact of the variation* or the operation of *natural selection* assigns *causes* "for the rise of living forms, from low to high, from simple to complex, from protoplasm to simple plant and animal, from fish to flesh, from lower animal to higher animal, from brute to man; still less that it scientifically accounts for the formation of any organ, as eye, or hand, or brain." †

It may be stated further, as the outcome of the second lecture, that the "fore-ordination," the "ultimate purpose," the "superintending providence," the "overruling intervention" of a Supreme Being are not shown to be inconsistent with the gradual evolution of the course of Nature as maintained by scientific investigators, and, it may be added, admitted by eminent Christian Divines.

"The business of Science is with the course of Nature, not with interruptions of it, which must

* p. 72. † p. 73.

rest on their own special evidence. Still more it is the business of Science to question teaching by all seeming interruptions of it, and its privilege, to refer events and phenomena, not at the first, but in the last resort to *Divine Will.*" *

The extracts which follow explain Asa Gray's view of the relation of the doctrine of Evolution to the records of religion, and his own distinct belief of the essentials of the Christian religion.

"I accept Christianity on its own evidence (which I am not here to specify or justify), and I am yet to learn how physical or any other science conflicts with it more than it conflicts with simple Theism. I take it that religion is based on the idea of a Divine Mind revealing Himself to intelligent creatures for moral ends."

"We shall perhaps agree that the revelation on which our religion is based is an example of evolution, that it has been developed by degrees and in stages, much of it in connection with second causes and human actions, and that the current of revelation has been mingled with the course of events. I suppose that the Old Testament carried the earlier revelation and the germs of Christianity, as the Apostles carried the treasures of the Gospel, in earthen vessels." †

"However we may differ in regard to the earlier stages of religious development, we shall

* p. 77. † p. 106.

agree in this, that revelation culminated, and for us most essentially consists in the advent of a Divine Person, who, being made man, manifests the Divine Nature in union with the human, and that this manifestation constitutes Christianity."

* * * *

"If now you ask me, What are the essentials of that Christianity, which is in my view as compatible with my evolutionary conceptions as with former scientific beliefs, it may suffice to answer that they are briefly summed up in the early Creeds of the Christian Church reasonably interpreted. The Creeds to be taken into account are only two—one commonly called the Apostles', the other the Nicene. The latter and larger is remarkable for its complete avoidance of conflict with physical science." *

The volume from which the foregoing extracts have been taken was kindly forwarded by Professor Asa Gray in the month of October 1887. In January 1888, it was followed by a simple memorial of his death.

DR. ASA GRAY,

BORN NOVEMBER 18TH, 1810;
DIED JANUARY 30TH, 1888.

"For thou, Lord, hast made me glad through thy work:
I will triumph in the works of thy hands."

* p. 108.

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THE END.

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OPINIONS OF THE PRESS.

Sir Thomas Dyke Acland's handy little book will be invaluable, for it combines the theory of the new school with the practice of the old, and its science is so carefully reduced to popular phraseology that no one runs any risk of not understanding it or finding it wanting in clearness. The Author claims for his work—"That no chemical element or compound is named which does not directly concern the farmer; that every chemical formula is accompanied by a statement of quantities in common arithmetical figures; and that a practical explanation of scientific weights and measures is given in terms with which farmers are familiar." —*County Council Times.*

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